PHYSICAL CONDITIONS AFFECTING STARCH
GELATINIZATION IN CORN AND SORGHUM GRAIN

by

FRED ROGER ANSTAETT

B. S. Kansas State University, 1966

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Grain Science and Industry

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1968

Approved by:

Harry B. Pfost
Major Professor

TABLE OF CONTENTS

	Page
INTRODUCTION	1
REVIEW OF LITERATURE	3
Starch	3
Factors Causing Gelatinization	4
Processed Grain	5
MATERIALS AND METHODS	14
RESULTS	27
DISCUSSION	49
SUMMARY	52
ACKNOWLEDGMENTS	53
LITERATURE CITED	54

INTRODUCTION

An increased interest has been shown in recent years to find a way to increase the feed efficiency and rate of gain of livestock on high concentrate rations. Since the major constituent of a high concentrate ration is the cereal grain in the ration, any process that would improve the utilization of the grain in the ration should improve the utilization of the entire ration.

It is well known that starch is the major constituent of cereal grain. Therefore, any change in the starch and/or the availability of the starch due to processing should play an important role in the utilization of the grain.

A number of studies have indicated that grain for beef cattle must be processed in some way other than the conventional methods of cracking or grinding if maximum feed efficiency and increased rate of gain are to be realized (14, 16, 20, 24). Studies have also been conducted with sheep (26, 27, 30), dairy cattle (12), and swine (2, 19).

Grain processing has taken many forms, from simple grinding to complex hydro-thermal treatments. A hydro-thermal treatment is defined as the addition of moisture to the grain to levels above that usually found in stored grain and then processed at temperatures above atmospheric temperatures. Hydro-thermal treatment is usually accomplished by the addition of steam to the grain. The addition of steam adds some or all of the moisture and the heat needed at the same time. The effects of these various grain treatments on feed intake, feed efficiency and rate of gain are different.

Hydro-thermal treatments of the grain with steam followed by either rolling to form a flat flake or extrusion to cause expansion of the grain are receiving the most attention at the present time (13, 15, 24, 38). Hydration or gelatinization of the starch is caused by hydro-thermal treatment and/or mechanical processing. This hydro-thermal treatment of the grain ranges from low-pressure high-moisture to high-pressure steam treatment. The duration of treatment and equipment involved varies from study to study.

The object of this study was to evaluate the degree of chemical change in the starch of the grain due to the effects of temperature, moisture and duration of treatment. Urea was included in the study because it is commonly used as a source of non-protein nitrogen for ruminants (34) and may also aid or contribute to the gelatinization of the starch in the grain (3).

REVIEW OF LITERATURE

Starch

Sung (36) reported on information available on the difference in the physical and chemical properties of starch, the structure of starch granules, and the different fractions of starch. Starch is composed of linear (amylose) and branched (amylopectin) molecules associated by hydrogen bonding. These hydrogen bonds are either derived directly from the starch chains or from the water present in crystalline.

The work of various cereal chemists on gelatinization of starch was reviewed by Sung (36). The gelatinization of a particular type of starch occurs over a temperature range of 7°-10°C. The gelatinization temperature varies for different types of starches. It has been reported that the starch in corn is gelatinized in the temperature range of 60°-72°C and sorghum grain starch gelatinizes between 68.5°C and 75°C. Measurements used to determine the gelatinization temperature of starch have included increase in optical transittancy, changes of viscosity, measurement of maltose produced by amylases, loss of birefringence, and recently the Köfler hot stage has also been used to provide a simple and sensitive way to determine the temperature at which starch gelatinized. MacMasters (23) states that staining with a Congo red solution can be used to determine the gelatinization temperature of various starches.

Researchers report that for the starch granule to swell freely without mechanical disintegration through contact with other granules excess water is needed. To produce a paste at 90°C in which the swollen granules occupy the entire volume, one hundred grams of water are required for 4.4 and 4.8 grams of corn and sorghum grain, respectively (21). However, Erwin (8) reports that even though most cereal technologists feel cooking of a cereal for human consumption requires the presence of at least 30-40% moisture, it has been found recently that cereals can be totally cooked with a moisture content of less than 20%. Sung (36) reports that pure starches gelatinize more readily than starch in whole grain and that the moisture content of the starch was an important factor in affecting the physical change.

The principal source of carbohydrate available for animals is starch. Starch granules occur in leaves, seeds, roots, fruits, tubers, and other parts of most green plants. Walker (3) reports that in a cereal grain, the outer bran layers and a protein-rich aleurone layer surround and protect the endosperm cells containing starch granules. The whole grain must be dealt with when considering improvements in the utilization of any one fraction of the kernel.

Factors Causing Gelatinization

There seems to be no uniform definition for gelatinization or the factors involved in gelatinization. Gelatinization is defined by Smith (32) as the complete rupturing of the starch granules brought about by a combination of moisture, heat, pressure, and, in some cases, mechanical shear. The factors involved in the low-pressure high-moisture steam treatment at or near atmospheric pressure followed by rolling are temperature, moisture, length of steaming time, and thinness of the flake (8). Erwin (8) states that the above mentioned variables plus the cooking pressure are critical in the pressure cooking of grains. Matsushima (24) considers the following factors to be important in the flaking process: type or kind of grain, moisture content of grain prior to processing, temperature, length of steaming period, open chamber or pressure cooker, moisture of the rolled grain, and roll setting.

Processed Grain

The exact physical and chemical changes in the structure of starch of grain after various hydro-thermal or other treatments are not well known. It has been generally recognized that hydro-thermal treated grain when fed to certain animals will affect the utilization of the grain. The type of treatment seems to have an influence on the effects that are obtained.

Johnson et al. (20) reported that when flaked corn prepared by steaming the grain in an open vat for approximately 12 minutes at 93°C and then flattening between rolls set at "zero" clearance was compared to cracked corn, a doubling of water intake and a loss of the property of birefringence in 30 to 40% of the starch granules was observed in the flaked corn. Rate of passage was significantly faster for the flaked corn when fed to fattening steers. When 70 to 80% corn rations were fed the dry matter digestibility of the flaked corn rations was 5% greater. No difference in the utilization of metabolizable energy was observed.

Cattle and sheep both showed significantly increased digestibilities of dry matter, organic matter, nonprotein organic matter, starch and reducing sugars, and energy in diets containing steam-processed sorghum grain when compared to diets containing finely-or coarsely- ground sorghum grain reports Buchanon-Smith et al. (4).

The percent starch digestion for sorghum grain and barley as affected by various processing conditions is reported by Osman et al. (28). They reported that steam processing for twenty minutes at atmospheric pressure or pressure cooking at 1.4 or 2.8 kg/cm^2 for one minute significantly decreased in vitro starch digestion in sorghum grain and barley. However, pressure cooking at 4.2 kg/cm^2 for one minute significantly increased starch digestion for both grains. Starch digestion for sorghum grain was increased further by pressure cooking at 5.6 kg/cm^2 for one minute. Flaking the grain by passing it through a roller mill after steaming or pressure cooking significantly increased starch digestion. Digestibility was increased as the thickness of the flake decreased.

Mehen et al. (25) compared the digestibility of steer rations containing 77% sorghum grain. The sorghum grain was prepared in four different ways: dry rolled, fine ground, steam processed at atmospheric pressure for 20 minutes then rolled, and pressure cooked at 2.8 kg/cm^2 for one minute then rolled. Digestion coefficients for dry matter, gross energy, and crude protein were not significantly different between dry rolled versus fine ground or between steam processed versus pressure cooked. They did report that dry matter and gross energy digestibility were significantly increased when dry rolled and fine ground were compared with steam processed and pressure cooked.

Beef cattle on a fattening ration containing 84% cracked sorghum grain was compared with a similar ration in which 40% of the cracked sorghum grain was replaced by popped sorghum grain by Ellis and Carpenter (7). They reported that the group on popped sorghum grain gained slightly slower than the group on cracked sorghum grain but required 16.6% less feed per kilogram of gain.

Various levels of gelatinized sorghum grain processed in an extruder cooker were compared by Drake et al. (5) in diets where sorghum grain made up 70% of the steer fattening ration. The gelatinized sorghum grain was fed as 0, 25, 50 and 75% of the concentrate. The ground sorghum grain was steam heated to 300°F and processed at a rate of about 900 kg. per hour. The cooked grain contained 18 to 20% moisture when it came from the cooker. They reported little variation in feed consumption among the various rations. Carcass grade did indicate a slight advantage for those steers receiving 50 and 75% gelatinized sorghum grain.

Woods and Wilson reported (39) that when gelatinized corn was fed as 50% of the corn in a 68% corn basal ration for yearling steers daily gains were depressed. Daily gains were depressed further when 100% gelatinized corn was used. Feed consumption decreased and feed required per kilogram gain increased as the percentage of gelatinized grain in the ration increased.

Menzies _et al_. (26) fed 0, 15, 30 and 45% of the sorghum grain in a ration for fattening lambs as expanded sorghum grain. The expanded grain was processed at 300°F. They reported that the 30% expanded ration gave the best gains and that consumption decreased as the percentage of expanded grain in the ration increased.

The effects of expanding or pelleting feed upon heifer growth and feed digestibility was reported by Haelien _et al_. (12). The expanded grain was 50% yellow corn and 50% raw soybean. The expansion process was at 280°F, steam pressure 70 psi (pounds per square inch), and retention time of 15-30 seconds. These conditions were reported to be "equivalent to 4 hours in a pressure cooker." The digestibility of all organic nutrients was higher in the ration supplemented with the expanded grain. Feed and dry matter consumption was increased with the expanded grain. Rates of daily gain were also greater for the expanded group.

Woods (38) reports that when a 68% corn ration made with corn gelatinized at 350°F and 400-500 psi mechanical pressure was fed to steers, the rate of gain and feed consumption was significantly decreased.

On the basis of feedlot performance Preston and Pfander (30) report that steam-cracked corn is better than steam-flaked, ground, or pelleted corn for fattening lambs. The steam-flaked corn gave the most desirable distribution of fat.

Garrett (10) found no significant differences in response as measured by average daily gain, feed comsumption, and yield when ground and steam-rolled sorghum grain were compared for feedlot cattle.

Hale et al. (14) compared steam processed-rolled sorghum grain and dry-rolled sorghum grain and steam processed-rolled barley and dry-rolled barley in performance trials with steers. A digestion trial to compare steam processed-rolled sorghum grain and dry-rolled sorghum grain was also run. The steam processing was accomplished by subjecting the grain to low-pressure high-moisture steam for approximately 20 minutes before rolling. The chamber temperature was 99°C. The moisture contents of the sorghum grain and barley flakes were 18% and 20%, respectively. In the performance trials gains were significantly increased by steam processing and the feed required per 100 kg gain was less for the barley rations. Dry matter, nitrogen-free extract, and gross energy digestibilities and total digestibile nutrients were significantly greater for the steam processed-rolled sorghum grain ration than the dry-rolled sorghum grain ration.

Newland et al. (27) reported that when flaked corn processed at 250°F for 30 minutes was fed to steers and lambs gains were not influenced, intake was decreased, and feed efficiency was increased.

Little et al. (22) reports that flaking is better than grinding but not as good as pelleting when feeding corn to fattening beef cattle.

Steam-rolled corn decreased daily intake and increased feed efficiency when compared to ground and cracked corn in beef cattle rations used by Hentges _et al_. (18).

Erwin (8) reported on a series of experiments with sorghum grain processed under various conditions of steam pressure and time. Changes in the grain were evaluated by optical birefringence, moisture absorption, diastatic enzyme conversion, and the artificial rumen. Both whole grain and flaked grain were evaluated. The optical birefringence evaluation indicated that as steam pressure was increased at constant time the percent gelatinization increased. Flaking caused an increase in percent gelatinization over the whole grain at the same time and steam pressure. The moisture absorption tests showed that as steam pressure increased the percent moisture increased.

A marked increase in moisture absorption at steam pressure higher than 40 psi was observed. The 60 psi pressure and 1.5 minutes processing time was equivalent to the fully gelatinized control. (The fully gelatinized control was a sample that had been steeped in cold water for 24 hours to a moisture content of 37% then processed for 15.0 minutes at 30 psi steam pressure. It contained approximately 45% moisture after cooking.) The diastatic enzyme conversion tests showed similar results. The flaking process approximately doubled the amount of dextrose produced when compared to the whole grain. Artificial rumen fermentation rate assessment based on volatile fatty acid production by the rumen microflora indicated that increased cooking pressures (0, 20, 40, 60, 80 psi) produced faster fermentation. However, increasing cooking time from one to four minutes did not appear to play a major role in altering the fermentation.

Rations that contained 56% sorghum grain at varying high steam pressures were compared to atmospheric steamed grain in a palatability study. The cooked grain did not significantly alter the feed consumption.

The results of a feeding trial showed a 6% increase in feed conversion for sorghum grain processed at 60 psi for 1.5 minutes when compared to atmospheric steam processed sorghum grain in a 65% sorghum grain ration fed to steers. As processing steam pressure was increased (0, 30, 45, 60 psi) at a processing time of 1.5 minutes the ration digestibility was increased.

Flaked, popped, and cracked sorghum grain in all concentrate rations were compared by Durham et al. (6). The average daily gains were 1.27 kg, 1.12 kg, and 1.23 kg for the cracked, flaked, and popped sorghum grain, respectively. Feed conversions were reported to be almost identical for the three different processing methods. The daily feed consumption of the cattle on the flaked sorghum grain was significantly less than on the other two rations.

Erwin (9) reports that increasing time at atmospheric steam pressure processing increased the moisture absorption in corn, barley, and sorghum grain. Both pressure and time increased the ability of the flaked grain to absorb water except that the 75 psi processed barley and sorghum grain showed decreased absorption with increases in time. When the bulk densities of the flaked grains were measured corn and barley showed a decrease in bulk density up to steam pressures of 50 psi and processing times of one minute. At higher steam pressures and for increased processing times increased bulk densities were observed. The results were not necessarily the same with sorghum grain. Longer processing times and higher steam pressures gave marked reduction in flake fragility i.e. a more rigid flake could be produced if the whole grain was processed at a higher steam pressure for a longer period of time.

Starch digestion by diastatic enzyme showed small differences in rate of starch digestion of corn, barley, and sorghum grain processed at atmospheric steam pressure for various lengths of time. However, increasing the steam pressure gave marked increases in the rate of starch digestion. Flaking of the grain also increased the rate of starch digestion over that of the whole grain.

After steam pressure processing wheat, corn, barley, and sorghum grain for feedlot cattle under various conditions of steam pressure and time, Garrett et al. (11) reports that if steam pressure processing has an influence on animal response, any beneficial effect is likely to be small and probably not consistent. They also report that all feed grains may not react the same way and that some steam pressure processing methods can have deleterious effects on animal performance.

Since variable results have occurred with hydro-thermal processed grain, there are disagreements concerning the true effects of hydro-thermal processing. This work was undertaken to study some of the variables involved in hydro-thermal processing of feed grains and define their effect on gelatinization (damage) of starch. The development of new processing machinery requires that these variables be defined. By knowing the amount of starch damage before the feeding trials are performed correlations between amount of starch damage and animal response can be made. If the amount of starch damage can be correlated with animal response, then starch damage can be used as a quality control procedure in processing feed for livestock.

MATERIALS AND METHODS

At the beginning of this study factors to be tested, processing procedures, and tests for degree of gelatinization had to be established.

The factors investigated in this study were type of grain, moisture level of the grain before hydro-thermal processing, processing time, processing temperature as measured by the saturated steam pressure and urea level. Corn and sorghum grain were studied in this trial. The grams of water added per 100 grams of sample and the corresponding percent moisture in the sample before processing are given in Table I. The processing times studied were 0, 1, 5, 10 and 15 minutes. Table II gives the saturated steam pressures used in psig (pounds per square inch gage) and the corresponding processing temperatures taken from Steam Tables (17). The urea levels that were studied were 0, 5 and 10% of the total sample processed.

Lots of corn and sorghum grain to run all of the tests were obtained from the feed mill of the Grain Science and Industry Department at Kansas State University. These lots had been ground through a 1/8 inch screen on a hammer mill. A large lot was obtained at the beginning of the study so that the unprocessed grain would be the same throughout the study.

A 100 gram sample of grain was processed. If additional moisture was to be added to the grain, distilled water was added from a wash bottle. If the sample was to contain urea the weight of grain was reduced by the percentage of urea to be added

TABLE I

Moisture Additions and Corresponding Percent Moistures

Moisture Added, grams per 100 grams sample	Corn Moisture, %	Sorghum Grain Moisture, %
0	12.4	12.8
10	20.4	20.7
12	21.8	22.1
14	23.2	23.5
16	24.5	24.8
18	25.8	26.1
20	27.0	27.3

TABLE II

Steam Pressures and Corresponding Processing Temperatures

Steam Pressure, psig	Temperature, °C
0	100.0
15	121.0
25	130.4
35	138.1
45	144.6
50	147.6
75	160.0
85	164.2

and the corresponding weight of urea added. The sample was then mixed thoroughly and placed in a 9 by 9 inch aluminum foil tray.

The pressure vessel used to run the tests was 44 inches long and 12 inches in diameter. A diagram of the pressure vessel is shown in Figure 1. The steam inlet was at the bottom of the vessel and was opened and closed with a quick action valve. The pressure regulator was placed approximately 10 feet from the steam inlet to the pressure vessel. A quick action pressure release valve was placed on top of the vessel and a drain valve was placed in the bottom of the pressure vessel to drain off the condensate that accumulated in the vessel. A safety release valve and two pressure gages were placed in the top of the pressure vessel. Two pressure gages were used to check their accuracy.

The sample tray was 36 inches long, 11 inches wide, and 4 inches deep. The water tray was 34 inches long, 7½ inches wide, and 1 inch deep. The water tray was placed in the pressure vessel so that water could be kept in the vessel. With water in the vessel it could be assumed that the steam in the chamber was saturated and not superheated. If there had not been water in the vessel while it was being operated and the vessel were hot enough to prevent condensation of any of the steam entering the pressure vessel superheated conditions could have been reached and the steam temperature would have increased. If the steam were superheated it would no longer be a moist-heat treatment. As moisture was one of the critical variables a moist-heat treatment was desired at all times.

The procedure for preparing the pressure vessel for processing and the processing of the sample was as follows. The sample tray

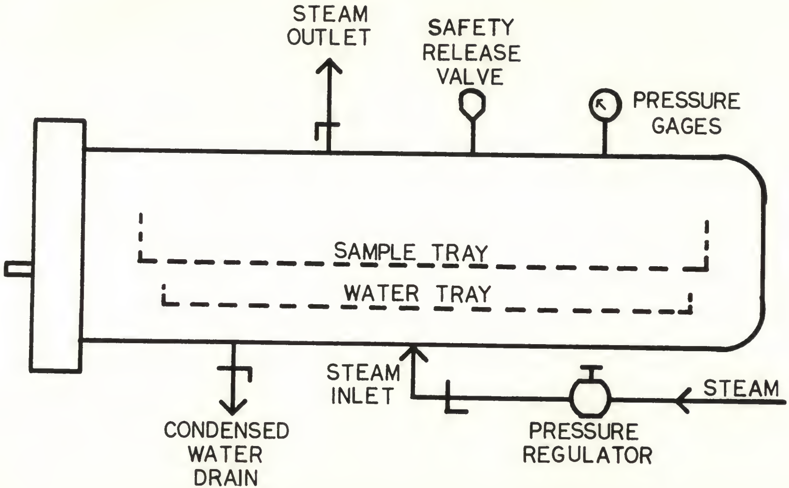

FIG. 1. PRESSURE PROCESSING VESSEL.

was placed in the pressure vessel, water was placed in the water tray and the door was closed. The drain valve and steam release valve were closed. The steam inlet valve was then opened to allow the steam to enter the vessel and the regulator was adjusted to the desired pressure. The steam inlet valve was shut off, the pressure released and the drain valve opened. Then the drain and release valves were closed and the steam inlet valve was opened again. This procedure was repeated several times to make sure the desired pressure was being obtained.

With the chamber hot and the pressure adjusted the door was opened and a check was made to be sure that there was water in the water tray. If not, additional water was placed in the tray.

The sample or samples to be processed at the same steam pressure and for the same length of time were then placed in the pressure vessel at one time. (Three was the maximum number of samples because condensed water tended to drip on the sample that was placed under the pressure release valve.) Each sample on a 9 by 9 inch aluminum foil tray was placed in the larger sample tray in the pressure vessel.

The door of the pressure vessel was closed after the samples had been placed in the tray and the steam inlet valve was opened to allow the pressure vessel to begin to fill with steam. The pressure release and drain valves were left open for a few seconds to flush the air out of the pressure vessel.

The reason for flushing the pressure vessel is that if the vessel is not flushed of air the temperature will not come up to the maximum temperature that is possible at any one pressure. This phenomenon is reported by Porter (29) on work by Underwood in 1941. If steam is applied at 15 pounds per square inch pressure to a completely evacuated sterilizer, a temperature of 250°F (121°C) is promptly attained. Evacuating one-half of the air before applying steam gives a final temperature of 234°F (112°C); removal of only one-third of the air allows a maximum temperature of 228°F (109°C); and when none of the air is removed, the maximum obtainable temperature, with 15 pounds per square inch steam pressure, is only 212°F (100°C). The decrease in temperature and increased time required to obtain the maximum temperature are shown graphically in Figure 2. After the pressure began to rise the release valve and drain valve were closed.

When the steam pressure was within five pounds per square inch of the desired pressure, time was started. It took approximately ten seconds for the pressure to reach this point at the lower pressures (less than 50 psig) and 15-20 seconds at the higher pressures (50-85 psig). As soon as the desired processing time was over the steam inlet valve was closed and the pressure release valve was opened. When the steam pressure had dropped to ten pounds per square inch the drain valve was opened. When the condensed water had drained out, the door was opened and the sample removed. If another sample was to be processed at the same pressure, it would be placed in the pressure vessel immediately without going through the warm up period again. Otherwise, the pressure vessel was warmed up before each trial.

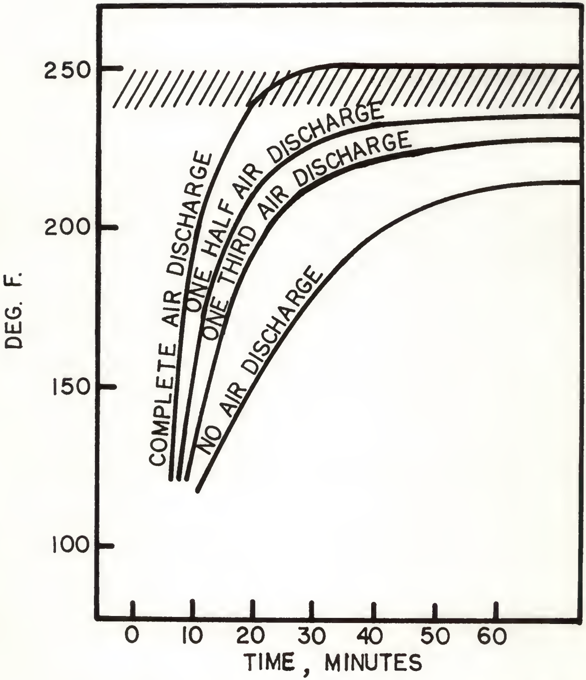

FIG. 2. EFFECT OF AIR IN STERILIZER UPON CHAMBER TEMPERATURE (FROM UNDERWOOD, 1941).

At the start of this study it was felt that a simple method for determining starch gelatinization should be used. Congo red (saturated in ethanol solution, pH8) has been reported (23) as a satisfactory stain for the determination of gelatinization. By observing the staining by Congo red under a microscope the amount of gelatinization can be determined. Congo red stains gelatinized granules and parts of granules but not ungelatinized granules.

In the microscopic evaluation of changes in the starch of the steam processed grain, a one gram sample of the processed grain was placed in 15-20 ml of distilled water and mixed in a Waring[R] blender for one minute at the high speed. The sample was then placed in a 100 ml beaker and a stirring rod was used to place one drop of the sample water mixture on a microscope slide. One drop of Congo red solution was then placed on the slide with the sample. A slide cover was placed over the sample and Congo red on the microscope slide. The slide was examined under a 200X microscope and the number of stained starch granules was compared with the number of starch granules that did not take the stain to determine the percentage of starch gelatinization.

Shortly after this study was started a method for determining the degree of starch gelatinization (damage) based on the availability of starch to enzyme hydrolysis (31, 33, 35) was developed by Sung (36). The method used for maltose estimation was a modification of the ferricyanide method for the determination of flour maltose values (1). The enzyme used was the major modification. Sixty milligrams of beta-amylase (product of Wallerstein Co., New York, New York) provided an excess of the enzyme in the tests (36).

One gram of the steam processed sample that had been ground through a one-sixteenth inch screen in a Wiley[R] mill and one-half teaspoon ignited quartz sand was placed in a 125 ml Erlenmeyer flask and rotated to mix. Forty milliliters sodium acetate-acetic acid buffer solution, at pH 4.6-4.8 and 30°C, was added to the sample and mixed thoroughly. Six milliliters of enzyme solution containing 60 mg. of beta-amylase was then added and mixed thoroughly. The digestion mixture was incubated in a thermostatically controlled water bath at 30°C ± 0.1°C for exactly two hours. At the end of the 2-hour period 2 ml of 3.58 N sulfuric acid was added and well mixed. Two milliliters of sodium tungstate was then added and well mixed. The solution was allowed to stand for 2 minutes and was then filtered. A 5 ml aliquot of the filtrate was transferred to a clean 80 ml test tube and 10 ml of 0.1 N alkaline ferricyanide reagent was added, mixed, and the test tube was placed in a boiling water bath for exactly 20 minutes. The water in the boiling water bath was only enough to come 2 to 3 cm above the contents of the test tube. The test tube and contents were cooled rapidly and 25 ml acetic-acid salt solution were added. The acetic-acid salt solution was added carefully because when it came into contact with the contents of the test tube it caused some frothing and if the acetic-acid salt solution was not added carefully the contents of the test tube would spill over. One milliliter of soluble starch potassium iodine indicator was added. The contents of the test tube were mixed thoroughly with a stirring rod and titrated with 0.1 N thiosulfate solution. The milliliters of 0.1 N ferricyanide reduced by the liberated reducing sugars was converted to milligrams maltose equivalents produced per gram of sample.

An expanded product that has been reported on by several workers (5, 26, 37, 39) was chosen as a goal for our processing. These workers reported that this was a fully gelatinized product. This product was obtained by processing grain on an expansion pellet mill at a temperature of approximately 300°F (149°C) obtained with steam. Additional water was added to the grain before and during the process. A mechanical pressure of 400 to 500 pounds per square inch was placed on the grain before it expanded and ruptured. Both corn and sorghum grain were expanded and gave a value of approximately 200 mg maltose equivalents produced per gram of sample by the above described method of enzyme hydrolysis. Both the expanded corn and expanded sorghum grain appeared to be 100% gelatinized when checked by the Congo red staining method.

In Experiment 1 corn was used and sorghum grain was used in Experiment 2. All possible combinations of 0, 10 and 20 grams added water per 100 grams sample; 1, 5 and 15 minutes processing time; and 0, 25 and 50 psig steam pressure were used. The processing conditions were replicated. The processed samples were air-dried, packed in plastic bags, and kept in the refrigerator at 10°C until analysis could be completed. The processed samples were analyzed by means of the Congo red staining method.

Corn and sorghum grain were processed in Experiments 3 and 4, respectively, at 15, 25, 35 and 45 psig steam pressure for 1, 5 and 10 minutes without any additional water added. Each processing condition was replicated. All processed samples were air-dried and stored in the refrigerator until analysis by the Congo red staining method could be completed.

In Experiment 5 corn was processed for 1, 5 and 10 minutes at 0, 25 and 50 psig steam pressure. Moisture additions of 0, 10 and 20 grams water per 100 grams sample were made. After processing, the samples were air-dried, and a portion of the sample taken for analysis by Congo red staining. The rest of the sample was ground through a Wiley[R] mill for enzymatic evaluation. All samples were stored at 10°C in the refrigerator until the analysis could be completed.

Sorghum grain was used in Experiment 6 to study the effects of processing at 0, 25 and 50 psig steam pressure for 1, 5 and 10 minutes. Moisture additions of 0, 10 and 20 grams added water per 100 grams sample were made. The processed samples were prepared for analysis as described for Experiment 5.

In order to observe the effects of urea addition on changes in the starch of the grain Experiments 7 and 8 using corn and sorghum grain, respectively, were designed. Urea was added to the ground grain at 0, 5 and 10% levels and mixed thoroughly before processing. Moisture additions of 0, 10 and 20 grams water added per 100 grams sample were made. Each of the samples was processed at 0, 25 and 50 psig steam pressure for 5 minutes. The processed samples were air-dried, ground and stored in the refrigerator until enzyme hydrolysis analyses could be completed.

Experiments 9 and 10 were designed to study the effect of higher steam pressures on starch damage in corn and sorghum grain respectively. The samples were processed for 1 and 10 minutes at 50 and 75 psig steam pressure with moisture additions of 0, 10 and 20 grams water per 100 grams sample. All processing conditions were replicated. After the processed samples were air-dried the samples were split and a portion placed in the refrigerator to be analyzed by the Congo red staining method. The rest of the sample was ground through the Wiley[R] mill and stored in the refrigerator until analysis by enzyme hydrolysis could be made.

Corn was used in Experiment 11 to study the effects of higher steam pressures and moisture additions between 10 and 20 grams added moisture per 100 grams of sample. Processing times of 1 and 10 minutes were used. The steam pressures studied were 75 and 85 psig. The moisture additions made were 0, 10, 12, 14, 16, 16, 18 and 20 grams water per 100 grams sample. Replication of each processing condition was made. The processed samples were air-dried, ground, and stored in the refrigerator until the enzymatic evaluations could be completed.

Sorghum grain was used in Experiment 12 to evaluate the same factors that were studied in Experiment 11. The samples were prepared and processed in the same way as in Experiment 11.

To determine the effects of mechanical pressure without the addition of heat or moisture, Experiment 13 was run. A sample of ground corn was placed in a cylinder with a piston and various amounts of pressure were applied. Tests were made at 0; 20,000; 40,000; 60,000; and 80,000 pounds per square inch. The resulting pellet was approximately 1.5 inches long by 0.75 inches in diameter. The pellets were ground and evaluation of starch damage was made by enzymatic hydrolysis.

Experiment 14 was performed to study the effects of atmospheric steaming and flaking, as performed at feedlots in the state of Kansas, of the whole grain. Samples were obtained from two feedlots in the state. Samples were taken of the grain before any processing was done, after the grain had been steamed, after the grain was flaked, and after the grain had been lifted by pneumatic conveying equipment to the storage bin. At feedlot A, one sample of sorghum grain after the various processes was obtained. One sample of corn and samples of sorghum grain from two flows were obtained from feedlot B. The samples obtained were ground through the Wiley[R] mill and moisture determinations made. Enzymatic evaluations were made and the results corrected to a dry basis.

RESULTS

The data from the experiments are shown in the following tables and figures. The "A" and "B" designation on the times stand for replications at the same processing conditions. In Experiments 1 and 2, Tables III and IV, it was found that when processing at 50 psig (pounds per square inch gage) steam pressure under any conditions of time and moisture addition tested there was one hundred per cent starch gelatinization when measured by Congo red staining for both corn and sorghum grain. Processing at 25 psig steam pressure produced more starch gelatinization than 0 psig steam pressure at all times and moisture additions. Processing at 25 psig pressure with 20 grams added moisture per 100 gram sample appears to give almost complete starch gelatinization at all processing times. The addition of moisture appeared to have an effect on the amount of starch gelatinization as measured by Congo red staining. Increases in processing time did not appear to have any effect on the amount of starch damage.

In Experiments 3 and 4, Tables V and VI, as steam pressure was increased starch damage increased. Increased processing time increased the amount of starch gelatinization as measured by Congo red staining.

In Experiment 5, Tables VII and VIII, Congo red staining showed that processing at 50 psig steam pressure with 20 grams added moisture per 100 grams sample at any of the tested processing times gave complete gelatinization of the starch

TABLE III

Effect of Moisture Addition, Steam Pressure and Processing Time on Starch Gelatinization of Hydro-Thermal Processed Corn as Measured by Congo Red Staining

Processing Time, Minutes	Steam Pressure, psig								
	0			25			50		
	Added Moisture, grams/100 grams sample								
	0	10	20	0	10	20	0	10	20
	Percent Gelatinization								
1-A	10	30	10	5	90	95	100	100	100
1-B	20	30	10	90	60	100	100	100	100
5-A	45	50	10	95	100	100	100	100	100
5-B	10	20	5	95	10	100	99	100	100
15-A	10	3	15	80	100	100	100	100	100
15-B	5	10	10	90	100	100	100	100	100

TABLE IV

Effect of Moisture Addition, Steam Pressure and Processing Time on Starch Gelatinization of Hydro-Thermal Processed Sorghum Grain as Measured by Congo Red Staining

Processing Time, Minutes	Steam Pressure, psig								
	0			25			50		
	Added Moisture, grams/100 grams sample								
	0	10	20	0	10	20	0	10	20
	Percent Gelatinization								
1-A	1	20	50	90	90	100	100	95	100
1-B	25	10	95	45	98	100	100	100	100
5-A	15	90	20	65	100	100	100	100	100
5-B	10	15	10	50	100	100	100	100	100
15-A	10	50	10	100	100	100	100	100	100
15-B	10	45	20	50	100	100	100	100	100

TABLE V

Effect of Steam Pressure and Processing Time on Starch Gelatinization of Hydro-Thermal Processed Corn as Measured by Congo Red Staining

Processing Time, Minutes	Steam Pressure, psig			
	15	25	35	45
	Percent Gelatinization			
1-A	2	5	15	50
1-B	5	40	20	50
5-A	3	15	40	80
5-B	15	50	60	75
10-A	10	20	30	95
10-B	25	40	60	95

TABLE VI

Effect of Steam Pressure and Processing Time on Starch Gelatinization of Hydro-Thermal Processed Sorghum Grain as Measured by Congo Red Staining

Processing Time, Minutes	Steam Pressure, psig			
	15	25	35	45
	Percent Gelatinization			
1-A	2	5	30	50
1-B	5	5	60	60
5-A	5	20	45	80
5-B	20	40	60	70
10-A	50	90	100	95
10-B	25	30	50	95

in corn. Similar results are shown for 5 or 10 minutes processing times at 50 psig and 10 grams added moisture per 100 grams sample, 10 minutes processing time at 50 psig steam pressure and no added moisture and 5 or 10 minutes processing time at 25 psig steam pressure with 20 grams added moisture per 100 grams sample. When these values are compared with the values obtained by enzyme hydrolysis, a range of values of 34 to 138 milligrams maltose equivalent produced per gram are found for the conditions that gave values of 100 per cent starch gelatinization by Congo red staining. A comparison of the Congo red staining method and the enzymatic method is shown in Figure 3. From work done with the control it was known that a value of at least 200 milligrams maltose equivalents produced per gram of sample could be obtained before complete gelatinization was reached. The enzyme hydrolysis method indicates that steam pressure of 50 psig, moisture additions and processing time of 5 or 10 minutes are required before any major changes in the starch occur.

In Experiment 6, Table IX and X, with sorghum grain the results were similar to those obtained in Experiment 5 with corn. A range of processing conditions indicated 100 per cent starch gelatinization by the Congo red staining method. While these same conditions gave a range of values from 38 to 158 milligrams maltose equivalent produced per gram of sample. A comparison of the two methods of starch damage determination are shown in Figure 4. The enzymatic determination indicates that the processing steam pressure must be 50 psig and

TABLE VII

Effect of Moisture Addition, Steam Pressure and Processing Time on Starch Gelatinization of Hydro-Thermal Processed Corn as Measured by Congo Red Staining

Processing Time, Minutes	Steam Pressure, psig								
	0			25			50		
	Added Moisture, grams/100 grams sample								
	0	10	20	0	10	20	0	10	20
	Percent Gelatinization								
1	5	3	5	20	10	35	65	80	100
5	20	18	28	18	75	100	95	100	100
10	10	15	30	50	80	100	100	100	100

TABLE VIII

Effect of Moisture Addition, Steam Pressure and Processing Time on Starch Gelatinization of Hydro-Thermal Processed Corn as Measured by Enzyme Hydrolysis

Processing Time, Minutes	Steam Pressure, psig								
	0			25			50		
	Added Moisture, grams/100 grams sample								
	0	10	20	0	10	20	0	10	20
	Milligrams maltose equivalent per gram								
1	34	32	34	27	29	35	27	42	65
5	23	19	22	16	30	34	38	109	118
10	20	23	32	47	32	61	41	88	138

TABLE IX

Effect of Moisture Addition, Steam Pressure and Processing Time on Starch Gelatinization of Hydro-Thermal Processed Sorghum Grain as Measured by Congo Red Staining

Processing Time, Minutes	Steam Pressure, psig								
	0			25			50		
	Added Moisture, grams/100 grams sample								
	0	10	20	0	10	20	0	10	20
	Percent Gelatinization								
1	5	5	10	20	30	40	95	100	100
5	5	20	5	25	80	100	100	100	100
10	2	15	40	40	60	95	95	100	100

TABLE X

Effect of Moisture Addition, Steam Pressure and Processing Time on Starch Gelatinization of Hydro-Thermal Processed Sorghum Grain as Measured by Enzyme Hydrolysis

Processing Time, Minutes	Steam Pressure, psig								
	0			25			50		
	Added Moisture, grams/100 grams sample								
	0	10	20	0	10	20	0	10	20
	Milligrams maltose equivalent per gram								
1	32	27	29	23	25	33	26	66	136
5	27	21	23	20	44	88	38	127	119
10	18	21	30	20	29	60	33	103	158

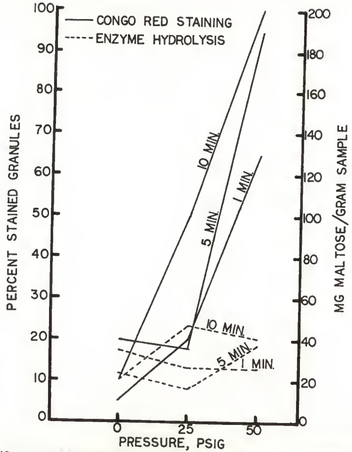

FIG. 3. COMPARISON OF TWO METHODS OF DETERMINING STARCH GELATINIZATION IN CORN.

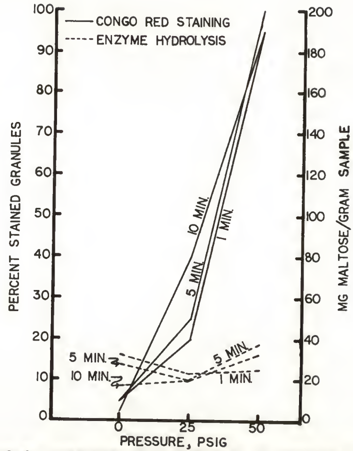

FIG. 4. COMPARISON OF TWO METHODS OF DETERMINING STARCH GELATINIZATION IN SORGHUM GRAIN.

moisture must be added before substantial increases in starch damage occur.

In Experiment 7, Table XI, the effects of urea, pressure and moisture were studied. The addition of urea at the levels studied did not appear to have any effect on changes in the starch of the corn. Pressure and moisture had the same effects as in Experiment 5.

In Experiment 8, Table XII, the addition of urea did cause an increase in the amount of damage to the starch of sorghum grain. Pressure and moisture had the same effects as in Experiment 6. Values of milligrams maltose equivalent produced per gram sample greater than 200, the value for the control, were obtained in this study indicating that starch damage above this can be obtained.

In Experiments 9 and 10, Tables XIII, XIV, XV, and XVI, a comparison of the two methods of determining starch damage shows results similar to Experiments 5 and 6. The Congo red staining method shows all samples completely or almost completely gelatinized. While the enzyme hydrolysis method gives a wide range of values. Comparisons of the two methods are shown in Figures 5 and 6. Increasing the steam pressure from 50 to 75 psig resulted in an increase in starch damage as measured by milligrams maltose equivalent produced by the action of beta-amylase on the starch in both corn and sorghum grain. Increasing the processing time from 1 to 10 minutes increased the amount of damage to the starch. Both corn and sorghum grain starch showed increases in the amount of damage

TABLE XI

Effect of Moisture Addition, Steam Pressure and Urea on Starch Gelatinization of Hydro-Thermal Processed Corn as Measured by Enzyme Hydrolysis*

Urea, %	Steam Pressure, psig 0			25			50		
	Added Moisture, grams/100 grams sample								
	0	10	20	0	10	20	0	10	20
	Milligrams maltose equivalent per gram								
0	23	19	22	17	30	34	38	109	117
5	36	43	43	29	37	47	38	41	86
10	38	56	57	37	48	49	47	74	103

* Processing time for all samples was 5 minutes

TABLE XII

Effect of Moisture Addition, Steam Pressure and Urea on Starch Gelatinization of Hydro-Thermal Processed Sorghum Grain as Measured by Enzyme Hydrolysis*

Urea, %	Steam Pressure, psig 0			25			50		
	Added Moisture, grams/100 grams sample								
	0	10	20	0	10	20	0	10	20
	Milligrams maltose equivalent per gram								
0	15	14	19	18	70	56	119	101	108
5	26	33	40	47	76	91	91	174	236
10	42	38	76	50	85	119	218	198	258

* Processing time for all samples was 5 minutes

TABLE XIII

Effect of Moisture Addition, Steam Pressure and Processing Time on Starch Gelatinization of Hydro-Thermal Processed Corn as Measured by Congo Red Staining

Processing Time, Minutes	Steam Pressure, psig					
	50			75		
	Added Moisture, grams/100 grams sample					
	0	10	20	0	10	20
	Percent Gelatinization					
1-A	100	100	100	100	100	100
1-B	100	100	100	100	100	100
10-A	100	100	100	100	100	100
10-B	100	100	100	100	100	100

TABLE XIV

Effect of Moisture Addition, Steam Pressure and Processing Time on Starch Gelatinization of Hydro-Thermal Processed Corn as Measured by Enzyme Hydrolysis

Processing Time, Minutes	Steam Pressure, psig					
	50			75		
	Added Moisture, grams/100 grams sample					
	0	10	20	0	10	20
	Milligrams maltose equivalent per gram					
1-A	52	109	114	131	193	259
1-B	43	96	133	129	181	242
10-A	76	191	196	186	257	256
10-B	116	189	203	181	249	259

TABLE XV

Effect of Moisture Addition, Steam Pressure and Processing Time on Starch Gelatinization of Hydro-Thermal Processed Sorghum Grain as Measured by Congo Red Staining

Processing Time, Minutes	Steam Pressure, psig					
	50			75		
	Added Moisture, grams/100 grams sample					
	0	10	20	0	10	20
	Percent Gelatinization					
1-A	90	95	100	100	100	100
1-B	95	100	100	100	100	100
10-A	100	100	100	100	100	100
10-B	100	100	100	100	100	100

TABLE XVI

Effect of Moisture Addition, Steam Pressure and Processing Time on Starch Gelatinization of Hydro-Thermal Processed Sorghum Grain as Measured by Enzyme Hydrolysis

Processing Time, Minutes	Steam Pressure, psig					
	50			75		
	Added Moisture, grams/100 grams sample					
	0	10	20	0	10	20
	Milligrams maltose equivalent per gram					
1-A	44	90	82	108	190	239
1-B	46	135	184	130	190	239
10-A	151	226	210	200	281	85
10-B	149	225	179	199	256	206

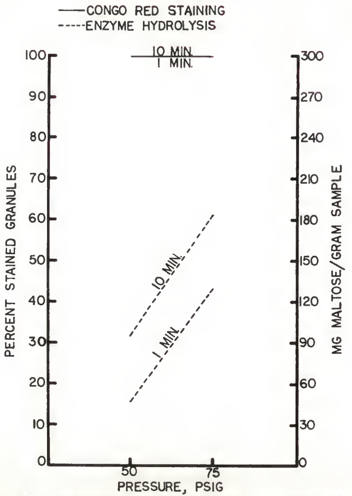

FIG. 5. COMPARISON OF TWO METHODS OF DETERMINING STARCH GELATINIZATION IN CORN.

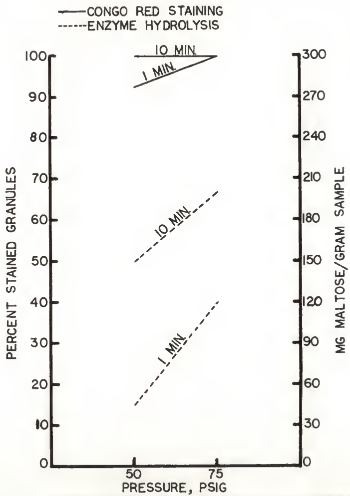

FIG. 6. COMPARISON OF TWO METHODS OF DETERMINING STARCH GELATINIZATION IN SORGHUM GRAIN.

as measured by enzyme hydrolysis with the addition of moisture. The results of these two experiments indicate that under certain processing conditions starch damage as measured by milligrams maltose equivalent produced per gram sample can be greater than 200. This was the value for our control which we assumed to be completely gelatinized.

In Experiment 11, Table XVII and Figures 7 and 8, the effects of processing at 75 and 85 psig steam pressure for 1 or 10 minutes with 0, 10, 12, 14, 16, 18 and 20 grams added moisture per 100 grams sample were studied. The starch in the corn showed more damage when processing time was increased from 1 to 10 minutes at 75 psig steam pressure. Moisture addition of 10 grams per 100 grams sample increased starch damage in the corn. Further moisture additions to the corn processed at 75 psig steam pressure had little effect until a level of 16 grams added moisture per 100 grams sample was reached. The addition of more moisture to the sample caused a decrease in the amount of starch damage. The results of processing corn at a steam pressure of 85 psig for 1 minute show an increase in starch damage over processing at 75 psig steam pressure. The addition of more than 10 grams moisture per 100 grams sample produced a decrease in starch damage of corn as measured by enzyme hydrolysis when processing for 10 minutes at a steam pressure of 85 psig. Several of the processing conditions gave results at or above the value obtained for the control (200 milligrams maltose equivalent produced per gram sample).

TABLE XVII

Effect of Moisture Addition, Steam Pressure and Processing Time on Starch Gelatinization of Hydro- Thermal Processed Corn as Measured by Enzyme Hydrolysis

Moisture Added, grams/ 100 grams	Steam Pressure, psig							
	75				85			
	Processing Time, Minutes							
	1-A	1-B	10-A	10-B	1-A	1-B	10-A	10-B
	Milligrams maltose equivalent per gram							
0	80	72	204	200	127	133	233	167
10	161	181	264	239	199	191	285	236
12	190	151	254	204	203	216	272	111
14	174	202	251	219	228	217	186	176
16	187	202	251	255	249	34	192	277
18	174	197	213	104	237	266	142	50
20	150	175	187	131	169	256	176	139

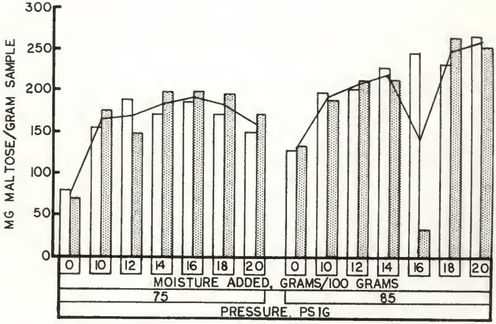

FIG. 7. EFFECT OF PROCESSING CONDITIONS ON CORN PROCESSED FOR 1 MINUTE.

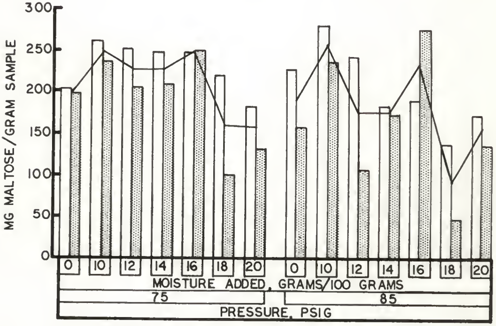

FIG. 8. EFFECT OF PROCESSING CONDITIONS ON CORN PROCESSED FOR 10 MINUTES.

In Experiment 12, Table XVIII and Figures 9 and 10, increasing steam pressure from 75 to 85 psig resulted in increases in the amount of damage to the starch in sorghum grain as measured by enzyme hydrolysis. At a processing time of 1 minute an increase in moisture addition resulted in an increase in the amount of starch damage at both 75 and 85 psig steam pressure. Moisture additions above 12 grams per 100 grams sample caused no further increases in the amount of starch damage when processing at 75 psig steam pressure for 10 minutes. At a steam pressure of 85 psig and processing time of 10 minutes the addition of 10 grams moisture per 100 grams sample increased the amount of starch damage while further increase in moisture addition had no effect or decreased the amount of damage to the starch of sorghum grain as measured by enzyme hydrolysis. Values of 200 milligrams of maltose equivalent produced per gram of sample or larger resulted from several of the processing conditions.

In Experiment 13, Table XIX, there was no effect on damage of starch in corn due to the application of pressure without the addition of heat or moisture as measured by milligrams maltose equivalents produced by the action of beta-amylase on the grain.

In Experiment 14, Table XX and XXI, atmospheric steaming added an average of 5 per cent moisture to the grain. The sample lost an average of 2 per cent moisture during the flaking process. The evaluation by enzyme hydrolysis of the amount of starch damage to the atmospheric steamed and flaked grain showed no effect due to steaming. Any marked changes in starch damage occurred during the flaking process.

TABLE XVIII

Effect of Moisture Addition, Steam Pressure and Processing Time on Starch Gelatinization of Hydro-Thermal Processed Sorghum Grain as Measured by Enzyme Hydrolysis

Moisture Added, grams/ 100 grams	Steam Pressure, psig							
	75				85			
	Processing Time, Minutes							
	1-A	1-B	10-A	10-B	1-A	1-B	10-A	10-B
	Milligrams maltose equivalent per gram							
0	68	100	203	173	113	113	214	220
10	158	146	212	191	177	133	275	252
12	181	184	277	261	196	207	288	191
14	224	229	259	258	185	193	245	220
16	248	203	254	258	226	215	253	262
18	230	219	278	232	227	236	284	59
20	277	175	276	239	254	268	116	179

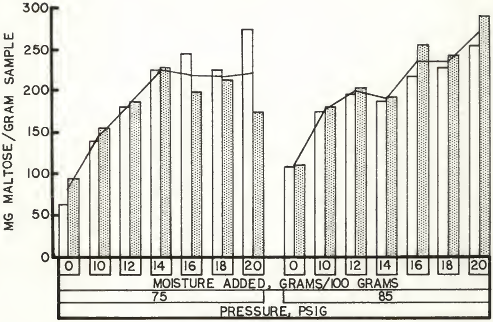

FIG. 9. EFFECT OF PROCESSING CONDITIONS ON SORGHUM GRAIN PROCESSED FOR 1 MINUTE.

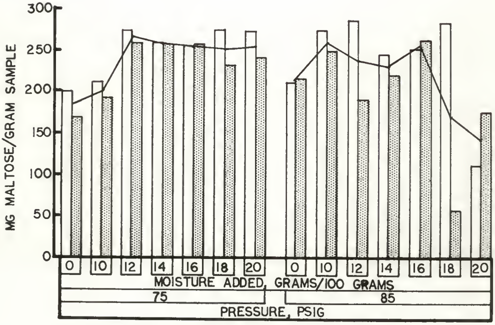

FIG. 10. EFFECT OF PROCESSING CONDITIONS ON SORGHUM GRAIN PROCESSED FOR 10 MINUTES.

TABLE XIX

Effect of Pressure Without the Addition of Heat or Moisture on Starch Gelatinization of Ground Corn as Measured by Enzyme Hydrolysis

Pressure, pounds per square inch	Milligrams maltose equivalents produced per gram of sample
0	26.2
20,000	34.5
40,000	29.3
60,000	35.2
80,000	30.8

TABLE XX

Effect of Atmospheric Steaming and Flaking on Moisture Content of Whole Corn and Sorghum Grain

Condition of the Grain	Feedlot A	Feedlot B		
	Sorghum Grain	Corn	Sorghum Grain-1	Sorghum Grain-2
		Moisture, %		
Whole	13.6	17.1	12.6	12.6
Steamed	17.8	22.1	17.5	18.4
Flaked	14.2	20.5	16.5	16.9
Air Lifted	14.6	20.6	15.5	16.0

TABLE XXI

Effect of Atmospheric Steaming and Flaking on Starch Gelatinization of Whole Corn and Sorghum Grain

Condition of the Grain	Feedlot A	Feedlot B		
	Sorghum Grain	Corn	Sorghum Grain-1	Sorghum Grain-2
	Milligrams maltose equivalents produced per gram			
Whole	43.4	37.2	40.6	40.3
Steamed	27.4	31.5	31.7	33.3
Flaked	164.3	96.1	87.2	73.3
Air Lifted	151.1	79.0	94.8	94.2

DISCUSSION

The results of two methods of determining amount of starch gelatinization (damage) indicated that the Congo red staining method was not suitable for determining the amount of starch gelatinization in whole grains. This may be due to the fact that in taking the sample to be examined from the beaker of water-sample mixture a higher percentage of the gelatinized starch was obtained. The starch granules that were loose from the larger particles of the sample would be more likely to be the damaged ones and the ones that were picked up on the stirring rod. If a larger particle or group of starch granules was placed on the slide not all of the starch granules could be seen and an accurate determination of starch gelatinization could not be made. As the evaluation of all of the starch in the grain was wanted rather than just an evaluation of that starch that was loose or visible on the outside of the larger particles of grain, the method based on the availability of the starch in the grain to enzyme hydrolysis appears to be more desirable for the determination of the amount of starch gelatinization due to different processing methods.

Steam pressure is an important factor in the hydro-thermal processing of grain. Within the limitations of these studies, increasing the steam pressure caused an increase in the amount of damage to the starch of the grain. However, the first 25 psig (pounds per square inch gage) steam pressure failed to produce major changes in the starch. There was little difference in the effect of steam pressure on corn and sorghum grain.

Moisture is considered extremely important to the gelatinization of starch (22). The results of this study indicate that the addition of more moisture to the grain increased the amount of gelatinization or damaged starch available to beta-amylase action. Except that when processing sorghum grain at 85 psig steam pressure for 10 minutes and processing corn for 10 minutes at 75 and 85 psig steam pressure the addition of high levels of moisture resulted in decreases in the amount of starch gelatinization.

The length of processing time also affected the amount of gelatinized starch; the longer the processing time, the higher the amount of starch gelatinized.

The addition of urea to the samples of corn did not affect the amount of starch gelatinization. However, when urea was added to the sorghum grain it caused an increase in the amount of starch gelatinization as measured by the availability of the starch in the grain to attack by beta-amylase. Differences in physical and chemical properties of the two grains may have been the reason for the different behavior of corn and sorghum grain.

The results of this study indicate that more starch damage than that obtained in our control can be obtained with the proper conditions of processing time, steam pressure and moisture addition. To obtain a product with an amount of starch damage equal to or greater than that of the control requires steam pressures of 75 or 85 psig. After the steam pressure has been determined the most critical variables in designing new equipment to process this product would be processing time and moisture addition. The processing time would determine the size of machinery required to produce the desired production rate. The amount of moisture addition would determine the need for drying and/or cooling equipment.

The application of pressure without the addition of heat or moisture showed no effect on starch gelatinization. The results of the atmospheric steaming and flaking show that the application of pressure after the addition of heat and moisture caused an increase in starch gelatinization. Therefore, under the limited observations in this study an interaction between heat and moisture and the application of pressure appears to occur.

SUMMARY

The effect of steam pressure, moisture addition, processing time and urea on the gelatinization of starch in hydro-thermal processed corn and sorghum grain was studied. Congo red staining and susceptibility to beta-amylase of the starch in the hydro-thermal processed grain was used for measuring the amount of starch gelatinization.

The Congo red staining method of determining starch gelatinization was found to be an unacceptable method of determining the damage of the starch of the grain.

The effect of steam pressure on starch gelatinization was to increase it as steam pressure increased from 25 to 85 psig (pounds per square inch gage). Steam pressure was not an important factor at 25 psig. Increasing processing time from 1 to 10 minutes increased starch gelatinization. Generally, the addition of moisture caused an increase in the amount of starch gelatinization. Within the limitations of this study, the amount of urea in the sample of sorghum grain had an influence on the amount of starch gelatinization, this effect was not found in the corn sample.

Conditions of steam pressure, moisture addition and processing time were found that would give starch gelatinization equal to or greater than that of the expanded product used as a control. This product has previously been reported as a fully gelatinized product.

ACKNOWLEDGMENTS

I would like to thank Dr. Harry B. Pfost, my major professor, for his guidance and assistance in the research and the preparation of this manuscript.

Funds for this project were furnished by W. R. Grace and Co.

Appreciation for use of the research facilities to conduct the study is extended to Dr. William J. Hoover, Head, Department of Grain Science and Industry.

Thanks are given to Dr. Charles W. Deyoe and Dr. Herbert T. Bates for serving on the advisory committee and reviewing the manuscript.

Thanks are extended to Dr. Majel M. MacMasters and Gerald D. Miller for their assistance with this research.

I also wish to thank An-Chein Sung for her assistance in running the chemical analysis on the samples. Thanks are extended to other members of the faculty and staff who gave assistance.

LITERATURE CITED

1. American Association of Cereal Chemists Cereal Laboratory Methods. 7th Ed. 1962. The Association: St. Paul, Minn.

2. Anonymous
Cooked Grain, In Feeding and Management Research Reports. Feedstuffs, Vol. 38, No. 47, p. 43. (Nov. 26, 1966).

3. Berglund, Roger
Heat Processing of Grain for Beef Cattle Discussed at Pacific S. W. Conference. Feedstuffs, Vol. 39, No. 1, p. 12 (Jan. 7, 1967).

4. Buchanan-Smith, Jack G., Robert Totusek and A. D. Tillman
Effect of Methods of Processing Milo on Its Digestibility and Utilization by Ruminants. J. Anim. Sci. 26:915 abstr. (1967).

5. Drake, C. L., B. E. Brent, C. W. Deyoe and H. B. Pfost
Graded Levels of Gelatinized Sorghum Grain in a Fattening Ration. J. Anim. Sci. 26:917 abstr (1967).

6. Durhan, Ralph M., George F. Ellis and Bobby Cude
A Comparison of Flaked, Popped and Cracked Milo in All Concentrate Rations. J. Anim. Sci. 26:220 abstr. (1967).

7. Ellis, George F., Jr. and James A. Carpenter, Jr.
Popped Milo in Fattening Ration for Beef Cattle. J. Anim. Sci. 25:594 abstr. (1966).

8. Erwin, E. S.
Pressure Cooking Grain for Cattle Ration. Feedstuffs, Vol. 38, No. 7, p. 60. (Feb. 19, 1966).

9. Erwin, E. S.
Processing Grain for Cattle. Feedstuffs, Vol. 39, No. 7, p. 29. (Feb. 18, 1967).

10. Garrett, W. N.
Comparative Feeding Value of Steam-Rolled or Ground Barley and Milo for Feedlot Cattle. J. Anim. Sci. 24:726-729 (1965).

11. Garrett, W. N., G. P. Lofgreen and J. L. Hull
Steam Pressure Processing of Wheat, Corn, Barley, and Milo for Feedlot Cattle. 1966 California Feeders' Day, p. 30-37 (1966).

12. Haelien, G. F. W., D. W. Burton, H. C. Hoyt, W. H. Mitchell and C. R. Richards.
Effects of Expanding or Pelleting Upon Feed Digestibility and Heifer Growth. J. Dairy Sci. 45:754-758 (1962).

13. Hale, W. H.
The Effect of Processing on the Feeding Value of Milo Grain for Ruminants. Proceedings of the 20th Annual Texas Nutrition Conference, pp. 25-39 (1965).

14. Hale, W. H., Luis Cuitun, W. J. Saba, Bruce Taylor and Brent Theurer
Effect of Steam Processing Milo and Barley on Digestion and Performance by Steers. J. Anim. Sci. 25:392-396 (1966).

15. Hale, W. H., and Bruce Taylor
Developments in Grain Processing. 1965 University of Arizona Cattle Feeders' Day, p. 42 (1965).

16. Hale, W. H., Bruce Taylor, W. J. Saba and Kenneth Palmer
The Effects of Steam Processing Milo and Barley and the Use of Various Levels of Fat with Steam-Processed Milo and Barley in High Concentrate Steer Fattening Rations. 1965 University of Arizona Cattle Feeders' Day, p. 16 (1965).

17. Handbook of Chemistry and Physics. 44th Ed. 1963.
The Chemical Rubber Publishing Co., Cleveland, Ohio. pp. 2539-2543.

18. Hentges, J. F., Jr., Margo Cabezas, A. Z. Palmer and J. W. Carpenter
Effect of Physical Form of Corn on Cattle Response. J. Anim. Sci. 20:935 abstr. (1961).

19. Hintz, H. F., and W. N. Garrett
Steam-Pressure Processing and Pelleting of Barley for Growing-Finishing Swine. J. Anim. Sci. 26:746 (1967).

20. Johnson, D. E., J. K. Matsushima and K. L. Knox
Utilization of Flaked vs. Cracked Corn by Steers. J. Anim. Sci. 26:876 abstr. (1967).

21. Leach, H. W., and T. T. Schoch
Structure of Starch Granule I. Swelling and Solubility. Cereal Chem. 36:534-544 (1959).

22. Little, C. O., N. W. Bradley and B. M. Jones
Ground, Flaked and Pelleted Corn for Fattening Beef Steers. University of Kentucky Progress Report, 116:12-14 (1962).

23. MacMasters, M. M.
Microscopic Techniques for Determining Starch Granule Properties. In Method in Carbohydrate Chemistry, R. L. Whistler Ed., 4:233-240 (1964).

24. Matsushima, J. K.
Grain Processing. Proceedings of the 21st Annual Texas Nutrition Conference, p. 141 (1966).

25. Mehen, S. M., W. H. Hale, Brent Theurer, Morgan Little and Bruce Taylor
Effect of Dry Rolling, Fine Grinding, Steam Processing Pressure Cooking on the Digestion of Milo Rations by Steers. J. Anim. Sci. 25:593 abstr. (1966).

26. Menzies, C. S., D. Richardson, C. W. Deyoe and H. B. Pfost
Effect of Heat Treatment of Proportions of Sorghum Grain in Fattening Lambs. Kansas State University 53rd Livestock Feeders' Day, pp. 51-52 (1966).

27. Newland, H. W., W. T. Magee, G. A. Branaman and L. H. Blakeslee
Effect of Heat-Processing and Pelleting Corn for Steers and Lambs. J. Anim. Sci. 21:711 (1962).

28. Osman, H. F., Brent Theurer, W. H. Hale and S. M. Mehen
Influence of Grain Processing on in vitro Enzymatic Starch Digestion of Barley and Milo. J. Anim. Sci. 25:593 abstr. (1966).

29. Porter, John Roger
Bacterial Chemistry and Physiology. John Wiley and Sons, Inc., New York, New York (1946).

30. Preston, R. L., and W. H. Pfander
Performance of Fattening Lambs Fed Various Forms of Corn. J. Anim. Sci. 20:947 abstr. (1961).

31. Sandstedt, R. L., and P. J. Mattern
Damaged Starch Quantitative Determination in Flour. Cereal Chem. 37:379-389 (1960).

32. Smith, O. B.
Factors in Conditioning Pellet Mash. Proceedings of the 1959 Feed Production School, p. 40, (1959).

33. Stamberg, O. E., and C. H. Bailey
Studies on Wheat Starch II. The Action of Amylases on Raw Wheat Starches. Cereal Chem. 16:319-330, (1939).

34. Stangel, H. J.
Urea and Non-Protein Nitrogen in Ruminant Nutrition. Chief Agriculturist. Nitrogen Division Allied Chemical Corp. 2nd Ed., (1963).

35. Sullivan, J. W., and J. A. Johnson
Measurement of Starch Gelatinization by Enzyme Susceptibility. Cereal Chem. 41:73-79, (1964).

36. Sung, An-Chein
Enzymatic Evaluation of Changes in Processed Grain. Unpublished Master's Thesis, Kansas State University, (1968).

37. Wilson, Ben B., and Walter Woods
Effect of Increasing Levels of Gelatinized Corn upon Rumen Metabolites. J. Anim. Sci. 26:932 abstr. (1967).

38. Woods, Walter
Recent Developments in Beef Cattle Feeding. 15th Annual Pfizer Research Conference Proceedings, p. 22, (1967).

39. Woods, Walter, and Ben B. Wilson
Influence of Level of Particle Size of Gelatinized Corn on Animal Performance and Rumen Fermentation. J. Anim. Sci. 26:933 abstr. (1967).

PHYSICAL CONDITIONS AFFECTING STARCH GELATINIZATION IN CORN AND SORGHUM GRAIN

by

FRED ROGER ANSTAETT

B. S. Kansas State University, 1966

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Grain Science and Industry

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1968

Hydro-thermal processing of feed grains to improve their value for livestock feeding has received increased attention in recent years. The methods of processing and the results obtained have varied from study to study.

The objective of this project was to evaluate the degree of chemical change in the starch of the grain due to the effects of temperature, moisture, processing time and urea. Ground sorghum grain and corn were processed at various steam pressures, with various amounts of moisture added for various lengths of time. Urea was added to one set of samples. Congo red staining and the availability of the starch to beta-amylase attack were used to determine the amount of starch damage obtained under the various processing conditions. The Congo red staining method for determining starch gelatinization was found to be ineffective for the determination of the amount of damage to the starch of the grain.

Increases in steam pressure from 25 to 85 psig (pounds per square inch gage) resulted in increases in the amount of starch gelatinization. At or below 25 psig steam pressure increases in starch gelatinization were not observed. There was little difference in the effect of the steam pressure on sorghum grain and corn.

The addition of moisture to the samples increased the amount of starch gelatinization in almost all cases. At steam pressures of 75 and 85 psig and a processing time of 10 minutes the addition of more than 10 grams moisture per 100 grams sample caused no further increases in starch gelatinization and in some cases caused a decrease.

The increase of processing time from 1 to 10 minutes resulted in an increase in the amount of starch gelatinization except at the higher levels of moisture addition at 75 and 85 psig steam pressure.

The addition of 5 per cent urea to the sorghum grain samples resulted in an increase in starch gelatinization. Addition of 10 per cent urea to the sorghum grain sample resulted in further increases in the amount of starch gelatinization. The addition of urea at either level had no effect on the starch of the corn.

Pressure was applied at various levels to corn samples without the addition of heat or moisture. No changes in starch gelatinization were observed. The atmospheric steaming and flaking of corn and sorghum grain gave an increase in starch gelatinization after the flaking process but not after the steaming process.

Steam pressure, processing time and moisture addition level combinations were found that would produce the same amount or more starch gelatinization as measured by the availability of the starch to beta-amylase attack than that of the expanded product that was used as a control.