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THE EFFECTS OF SULPHUR ON THE QUALITY OF WHEAT

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QUALITY OF WHEAT

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Francis Lloyd Rigby

INTRODUCTION

The protein content of wheat is not an ideal measure of baking strength for it takes into account only the total amount of protein present and is in no way a measure of the quality of the protein. In general application, protein content is the best single measure expressive of baking strength, apart from actual baking tests, but in particular cases it frequently proves inadequate in explaining loaf volume differences.

It is well known that differences in the quality of protein do exist. If such differences in quality of protein did not exist, then flours of equal protein content would be expected to produce loaves of equal volume, provided that a suitable baking formula is used. While in the majority of cases this rule holds true, there are many times when it does not. There must, then, be some other factor, or factors, almost certainly associated with the protein, which are responsible for these dis-

crepancies.

The crude glutens from hard wheats of different baking strengths generally vary in both quantity and physical properties. Particularly where the differences in baking strength are large, the physical properties of the glutens from high and low quality flours show very obvious differences. The gluten from poor quality flours lacks the cohesive, elastic, and extensible properties of that from strong flours.

Much research has been done in order to find an explanation as to why these differences in gluten quality occur. As yet, no entirely adequate answer has been found to this problem, though it has been attacked from a variety of angles.

Extensive physico-chemical studies have been carried out on doughs and glutens in attempts to establish sound criteria for evaluating the quality of gluten. However, no strictly chemical test as yet applied has been of value in differentiating between strong and weak glutens.

The gray wooded soils of Alberta are particularly noted for the production of wheat of inferior baking quality. In 1929 the Department of Soils of the University of Alberta commenced a series of experiments with various fertilizers at Breton, in the gray wooded soil area. (See Wyatt, Newton and Ignatieff, 26). The response in yield of crops to the

fertilizers containing sulphur was particularly notable. There was also a marked improvement in the baking strength of wheat grown on plots receiving a sulphur bearing fertilizer over those receiving fertilizers containing no sulphur. This difference was, in many cases, not explainable on the basis of protein content of the wheat. The evidence pointed to some quality factor in the gluten as being responsible for the wide range in baking strength.

The apparent improvement in the quality of the wheat as a result of a sulphur fertilizer, prompted a more critical study of this element and its compounds in the wheat itself.

The investigation was carried forth as outlined in the following report.

REVIEW OF LITERATURE

As nearly as can be determined, the literature reveals no information of significant value in indicating the probability or improbability of the sulphur content of wheat being a factor influencing the baking strength. In view of this, some of the literature reviewed may appear to be remotely connected with the problem. It does, however, give some knowledge of the metabolism of this element and the probable forms and quantities which are present in the plant.

As mentioned in the introduction, the remarkable

increases in baking strength of flours milled from wheat grown on the plots receiving sulphur bearing fertilizers, as compared with those receiving no sulphur, is illustrated by Wyatt, Newton and Ignatieff (26). They further show that the protein content appears to bear slight relation to the loaf volume in many cases.

Peters (17), working also with Breton material, has shown that sulphur fertilizer applications to crops results in higher sulphur content of the plant products, particularly in the case of legumes which have a high nitrogen requirement.

Wood and Barrien (24) state that the sulphate ion constitutes the sole source of sulphur to plants and that sulphur-containing proteins are the synthetic end-products in the sulphur metabolism.

Wood (25), in a later paper, further states that the only sulphur constituents of the protein molecule are the sulphur-containing amino acids, cystine and methionine.

These acids also occur in the free state in plant tissue, together with cysteine and glutathione which are derived from them. Cystine and methionine are present in approximately equal amounts in the plant tissue.

Hoffman and Gortner (14), 1922, state that cystine is the principal form of sulphur in proteins and that cysteine, as such, has never been proven to be present. They found evidence of some other form of sulphur being present.

Methionine, which may have represented the remainder was discovered only in the previous year, 1921.

Harrow (13) lists five sulphur containing amino acids, namely, methionine, cystine, ergothionine, lanthionine and djenkolic acid, which are found in biological substances. He classifies cysteine as a reduced form of cystine, of importance in biological reactions. It is formed readily upon the reduction of cystine.

In the literature reviewed, no reference could be found signifying the presence of ergothione, lanthionine or djenkolic acid in wheat or wheat products.

Cysteine is noted for its sulphydril group, (S-H), which is highly reactive due to the hydrogen being readily surrendered to oxidizing agents. The organic compounds of sulphur are frequently divided into two groups on this basis, that is, those containing S-H groups and those without. Where the sulphur is linked on both sides to a carbon atom, or to some atom other than hydrogen, the linkage is comparatively stable and is non-reducing.

In wheat, by far the most attention has been given to the S-H compounds. One of the sulphur compounds in wheat, glutathione, possesses a sulphydril group. Glutathione is a polypeptide of glutamic acid, glycine and cysteine. It occurs chiefly in the germ in wheat according to Sullivan, Howe and Schmalz (20), and no more than traces, if any, are found in

patent flours from commercial mills. The reducing capacity of the S-H group in glutathione is considered by Sullivan, Howe and Schmalz (21), and also Balls and Hale (1,2), to be responsible for the activation of some of the proteolytic enzymes in wheat with consequent deleterious effects on the baking quality. They further believe that the oxidation of this S-H group by heat treatment, aging and flour improvers, such as potassium bromate, at least partially explains the beneficial effect of these processes.

On the basis of experiments testing the rate of oxidation of glutathione by potassium bromate, Smith and Geddes (19), cast some doubt on the validity of this theory.

Myers and Working (16) tested flour protein fractions for the presence of S-H groups. In preliminary experiments, neither reactive nor unreactive S-H groups were found in the gluten proteins. The soluble portion of the protein was tested and only after denaturation were indications of the presence of unreactive S-H groups found. The presence of free S-H groups was found in the lipid fraction obtained upon ether extraction.

Greaves and Bracken (11), found no inorganic sulphur in wheat and concluded that all the sulphur was present in organic form. The range of sulphur content of the Utah varieties tested was 0.15% to 0.22%. A correlation coefficient

of 0.81 was found between sulphur and nitrogen content.

Gubler and Greaves (12), working also with Utah wheats, found percentages of cystine ranging from 0.338% to 0.405% in the whole wheat, with an average of 0.364%. A greater percentage of cystine was found in spring wheats than in winter wheats. When the data were subjected to statistical analysis, as much difference was found between different determinations on the same variety as between variety means. In general, variations in sulphur content were accompanied by corresponding variations in the cystine content. The higher percentage of cystine in spring wheats, as compared with that for winter wheats, was paralleled by a correspondingly higher average value for total sulphur and nitrogen. The variation between the highest and lowest value for total sulphur was about 46% of the mean whereas that for cystine was only 20%. Thus not as wide a range was obtained in the percentages of cystine as in those of sulphur. It was observed that the cystine sulphur constituted about 50% of the total sulphur, with the range from 47% to 66%. In general, as the total sulphur and cystine increased, there was a decrease in the percentage of the total sulphur represented as cystine. The coefficients of correlation found for sulphur and cystine and for nitrogen and cystine were highly significant.

Csonka (7) determined the amounts of several amino acids in three varieties of wheat grown in Ohio. Expressing the cystine found as milligrams per gram of nitrogen in the wheat he found:-

<u>Variety</u>	<u>Type</u>	<u>mg. Cystine per gm. Nitrogen</u>
Marquis	Hard red spring	81
Tenmarq	Hard red winter	65
Fulhio	Soft winter	67

Thus, cystine was present as a greater proportion of the protein in Marquis than in the winter wheats.

Barnstein (5), has developed methods for the determination of cystine and methionine and in applying them to purified cereal proteins, he obtained the following results:-

<u>Protein</u>	<u>Cystine %</u>	<u>Methionine %</u>	<u>Total Sulphur Accounted for %</u>
Monococcumin	2.23	3.04	109.4
Dicoccumin	2.65	2.78	109.2
Speltin	2.71	2.61	106.4
Durumin	2.34	3.39	108.5

These two amino acids, according to these figures, are present in approximately equal amounts and account for all of the sulphur in the protein.

MATERIALS

The wheat used in these experiments was of the Thatcher variety and was supplied through courtesy of the Department of Soils of the University of Alberta. It was grown on the Breton Experimental Field, in the gray wooded soil area of Alberta, seventy-five miles southwest of Edmonton. (For full details of the Breton Field Experiment consult Wyatt, Newton and Ignatieff 26).

The series "Wheat after Clovers" consistently has produced the greatest variations in baking strength and consequently it has been chosen for this study. Three years material were available, 1941 to 1943 inclusive.

All of the samples from the old Series, plots one to eleven, were used. The checks, samples 1, 5 and 11 were bulked together to form a representative check sample. Five samples from the new series, plots 13 to 26, were selected owing to their wide variations in loaf volume, and the relative amounts of nitrogen and sulphur fertilizers used. These plots were 13, 18, 19, 20 and 21. The checks, 13 and 18 were bulked as in the old series to give one check sample.

For cystine and methionine determinations, each of the 1941 and 1942 samples of similar sulphur content and loaf volume were bulked, in order to conserve the limited quantity of material and to reduce the number of samples.

The bulking was carried out as illustrated below:

1941 Material

Bulked Sample	COMPONENTS			Loaf Volume	Sulphur %
	Sample	Treatment			
1	(2	Manure	563	0.12	
2	(3	Complete	683	0.18	
	(4	Ammonium Sulphate	693	0.20	
	(9	Manure & 16-20	713	0.18	
	(10	16-20	673	0.17	
3	(6	Lime	438	0.12	
	(7	Lime & Phos.	440	0.14	
	(8	Triple Phos.	403	0.14	
4	(13 & 18	Check	525	0.14	
5	(19	Ammonium Nitrate	485	0.13	
6	(21	Gypsum	573	0.20	

1942 Material

1	(1	Check	588	0.13	
	(2	Manure	573	0.13	
2	(4	Amm. Sulphate	708	0.19	
	(9	Manure & 16-20	655	0.17	
	(10	16-20	613	0.17	
3	(6	Lime	553	0.11	
	(7	Lime & Triple	583	0.12	
4	(13 & 18	Check	655	0.13	
	(19	Ammon. Nitrate	640	0.10	
5	(20	Ammon. Nit. &) Gypsum)	760	0.19	
6	(21	Gypsum	730	0.18	

METHODS

Protein

Nitrogen was determined using the Kjeldahl-Gunning-Arnold method, with mercuric oxide as catalyst. The protein is N x 5.7, and results are reported on a 13.5% moisture basis.

Baking

Flour samples of 100 grams were baked using the malt-phosphate-bromate formula, with 0.3% diastatic malt, 0.1% ammonium phosphate and 0.001% potassium bromate.

Sulphur

The A.O.A.C. (15) method using nickel crucibles, open fusion and sodium peroxide was used, but the following modifications were introduced:

Seven grams of anhydrous sodium carbonate were added to the material at the outset. After moistening, sodium peroxide was added in small amounts until eight grams had been added, stirring constantly. The granular mixture was then allowed to stand over night. Following this, the mixture was heated over a low bunsen flame with constant stirring, until evolution of gas had ceased and the fusion

mixture was dark and pasty. Three grams of sodium peroxide were then added, and the covered crucible heated over increased flame for five minutes. The crucible was rotated until the contents had solidified and then placed in a 600 cc beaker and 100 cc of distilled water added immediately. This was followed with concentrated HCl, and the crucible was turned to bring all parts in contact with the solution. As the violent reaction subsided the acid was added carefully until the solution was just clear. The crucible was removed and rinsed thoroughly with distilled water.

The remaining steps were carried out in the regular manner.

Gluten Washing

The solution suggested by Dill and Alsberg (8), was used, namely, 4% sodium mono-phosphate adjusted to pH 6.8 by the addition of sodium di-phosphate. Using this as a stock solution, further dilution was made in the proportion of one part stock solution to forty parts of unboiled distilled water. Washing time was standardized at ten minutes for a 30 gram sample.

Cystine

The literature was reviewed with the object of

locating methods for the determination of cystine in this material. Although cystine has been determined quite extensively in biological material, little work has been done with wheat.

Two methods which offered possibilities of success were found. These were:

- (1) The colorimetric method of Gubler and Greaves (12), for the determination of cystine in whole wheat.
- (2) The gasometric method of Barnstein (3) for the determination of cystine in proteins.

(1) The Colorimetric Method

Gubler and Greaves reviewed methods for the determination of cystine in search for a method adaptable to wheat. They eventually decided upon the method of Folin and Looney (9), as modified by Shinohara (18). They added further modifications to this method in adapting it to wheat.

This method was followed in every detail according to the procedure outlined by Gubler and Greaves. Three difficulties were encountered in applying the method.

- (1) Directions for the preparation of the color reagent were not contained in the outline, nor were they available in any of the papers directly referred to by Gubler and Greaves. A method for the preparation of molybdate-free phospho-18- tungstic acid reagent was located in Folin and Marenzi (10). It was assumed that this was the color reagent used but this is not definitely known.

- (2) Complete directions were not given for the preparation of the color standard. In the literature cited, both cystine and cysteine hydrochloride were used in either hydrochloric or sulphuric acid solution. Both were tried here, however, with no perceptible difference in results.
- (3) A Bausch and Lomb colorimeter, as prescribed, was not available. The Ernst Leitz colorimeter used did not permit a wide range of color intensities in the unknowns without frequent changing of the color standard. Since the color-producing reaction requires strict adherence to a time schedule in making readings, the instrument was hardly suitable for even a moderate number of samples.

Table I shows some of the results obtained with this method. There is a decided lack of agreement among replicates, even between duplicate determinations on the same hydrolysate. The cystine percentages account for a smaller fraction of the total sulphur than was anticipated, but this may or may not be a fault of the method.

TABLE I

Colorimetric Determination of Cystine in Flour

<u>Sample</u>	<u>Cystine in Flour</u> <u>Replicates</u>			
1			0.179	0.077
2			0.251	0.166
3			0.143	0.050
4	0.193	0.155	0.304	0.130
5	0.247	0.185	0.391	0.224
6	<u>0.211</u>	<u>0.179</u>	0.110	0.156

Same hydrolysate

The method was applied to wheat gluten with slightly better agreement between duplicates, but with even lower percentage of the total sulphur represented.

Starch and gelatin mixtures were prepared and known amounts of pure cystine added. These samples were hydrolysed and the following recoveries obtained:

<u>Sample</u>	<u>Actual Cystine %</u>	<u>Cystine Found %</u>
1	6.6	0.44
2	3.3	0.15
3	0.0	Negative Quantity

Samples of urine were tested and found to average approximately ten milligrams of cystine per 200 cc. This is within the normal range and signifies that the method as used would probably have been successful on such mate-

rial.

The low recovery of cystine in the starch-gelatin mixtures, as compared with the presumably satisfactory determination on urine points to the probability of loss during hydrolysis. The only apparent chance for error in hydrolysis was the tendency for the material to produce humin nitrogen which collected in a charred mass on the sides of the hydrolysis flask. This material adhered so tightly that it could not be removed by washing down during hydrolysis. Glass beads were used to extract this residue from the flask upon the completion of hydrolysis.

(2) The Gasometric Method

This method was developed by Barnstein (3) for the determination of cystine in proteins. No attempt was made here to apply it to the whole wheat, but rather to the gluten as washed from the flour.

The gasometric apparatus was constructed in the laboratory according to the plan of Van Slyke and Neil (23). The trial determinations were performed on pure cystine and cysteine solutions.

Barnstein (3) states that at 25 °C. the change in pressure for 3.85 milligrams of cysteine or 3.79 milligrams of cystine is 48.1 plus or minus 0.7 millimeters of mercury. In other words, a change on pressure of approx-

imately 12.5 mm. is produced by one mg. of cysteine.

It is not clearly stated whether this means one milligram of cysteine in the total sample, in the aliquot oxidized by the iodine solution, or in the 1 cc. of iodine-sample mixture introduced into the apparatus.

The change in pressure for each 0.5 mg. of cysteine in the total sample was found here to be extremely small, less than 0.2 mm. For each mg. of cystine in the 2 cc. aliquot oxidized by the iodine solution the change in pressure was 11.4 mm. For each mg. introduced into the apparatus for testing it was 57 mm. Presumably Barnstein meant the aliquot oxidized by the iodine solution. However, there is still some lack of agreement.

The results in Table II show the change in pressure per increment of 0.1 mg. of cysteine in the one cc. sample introduced into the apparatus. Each figure is the mean of several determinations. The results are plotted graphically in Figure 1.

TABLE II

Change in Pressure for increments of Cysteine

<u>Cysteine mg.</u>	<u>Change in Pressure mm.</u>	<u>Cumulative Change</u>
0.1	4.0	4.0
0.2	5.5	9.5
0.3	5.5	15.0
0.4	5.5	20.5
0.5	6.0	26.5
0.6	5.5	32.0

Except for the first increment, the change in pressure for each additional increment is approximately the same. Theoretically, each increment should have produced the same change in pressure and the regression line should have passed through the zero point. The only explanation that can be offered is that part of the excess iodine was oxidized by some impurity either in the hydrochloric acid, the hydrazine solution or the mercury, with consequently less liberation of nitrogen gas.

Neglecting the first increment, the average change in pressure for each 0.1 mg. of cystine in the test solution was 5.7 mm.

Calculation of results was performed as follows:-

$$\left(\frac{\text{Change in pressure}}{5.7 \times 10} + 0.1 \right) 62.5 = \text{mg. cysteine in sample}$$

$$\text{mg. cysteine} \times 0.98442 = \text{mg. cystine}$$

Twelve samples of gluten were tested using this method and the results are presented in Table III.

Figure 1

This shows that a straight line relationship exists between the amount of cysteine in the test sample and the change in pressure due to gas released.

TABLE III

Gasometric Results

<u>Sample</u>	<u>Cystine in Gluten</u>	
	<u>Duplicates*</u>	
1	1.68	1.80
2	2.17	2.09
3	1.44	1.37
4	2.02	1.97
5	1.95	1.87
6	2.33	2.21
7	1.54	1.49
8	2.27	2.30
9	1.44	1.54
10	1.81	1.83
11	2.24	2.06
12	1.87	2.01

* Two results had to be discarded and repeat determinations made.

The standard error between duplicates is 4.6% of the mean.

Methionine

Only one method for the determination of methionine was located, namely, the method of Barnstein (4) for the determination of methionine in proteins.

Barnstein states that there is a possibility of the results not being absolute, since the ability of many substances, which may be present, to yield volatile iodides has not been fully investigated.

The method was applied here to samples of crude gluten in hope that it would give some indication of the relative amounts of methionine present.

The difficulties encountered were entirely mechanical:

- (1) Ground glass joints, as prescribed, were not procurable. For the boiling flasks, corks, charred corks and finally rubber stoppers were used. All showed considerable signs of deterioration by the hydriodic acid.
- (2) The carbon dioxide stream was delivered by a high pressure carbon dioxide cylinder, the rate of flow being regulated by the needle valve carried by the cylinder. The rate of flow was thus controlled with difficulty. Much more satisfactory control could have been made with a constant pressure valve of the type used on high pressure tanks.

The water was brought to 60°C by circulating it through a heating coil immersed in a constant temperature

oil bath with a constant head of pressure provided by an elevated reservoir. By adjusting the rate of outflow from the condensers, the temperature of the water could be maintained fairly constantly at 60°C.

The results of analyses obtained on six samples are reported in Table IV.

TABLE IV

Determination of Methionine

<u>Sample</u>	<u>Methionine %</u>	<u>Duplicates</u>
1	2.38	2.52
2	1.60	3.51
3	1.57	1.93
4	1.67	2.28
5	1.93	3.24
6	2.70	4.30

There is extremely poor agreement between duplicates in most cases. It is thought that this is mainly due to the apparatus. Since the average difference in titration between the sample and the blank was less than one cc. of 0.02 Normal KCNS, more precision of technique was required than was afforded by the apparatus.

With suitable apparatus, the method offers possibilities

of success for the purpose intended here, particularly if a more purified gluten is used.

RESULTS

1941 Material

The first experiments were carried out on the 1941 samples. Protein content, sulphur in whole wheat, sulphur in flour and sulphur in gluten were determined. The results are presented in Table V together with the loaf volume figures obtained for the bread baked from these samples.

The loaf volume ranges from 403 cc. to 750 cc. and the protein content from 11.6% to 14.1%. From even casual examination of the results it is apparent that the variations in loaf volume are not due to corresponding variations in protein content. Outstanding examples can be selected, such as Sample 19 with the highest protein content, 14.1%, and a very low loaf volume, 485 cc., as compared with Sample 20 with a much lower protein content, 12.8%, and the highest loaf volume, 750 cc. Sample 6 as compared with Sample 4 is a similar case. From the statistical calculations presented in Table VI, the correlation between protein content and loaf volume is not statistically significant. Some factor or factors other than protein content must be responsible for the differences.

The sulphur content of the wheat varies over a considerable range, from 0.12% to 0.22%. The high sulphur values are consistently associated with the high loaf volumes. Samples 19 and 20, 4 and 6, and some others, illustrate this apparent effect of sulphur on loaf volume. A highly significant correlation exists between the sulphur content of the whole wheat and the loaf volume.

The sulphur content of the flour follows closely that for the whole wheat but the level is slightly higher. This indicates that the sulphur is more concentrated in the endosperm of the kernel than in the whole wheat.

Samples of crude gluten were prepared from each flour and analysis for sulphur performed. A much higher level of sulphur is clearly shown, indicating that the sulphur in wheat is concentrated in the protein. The range of sulphur content is much greater in the gluten than in either the whole wheat or the flour. However, the glutes high in sulphur are quite regularly produced from the flours high in sulphur, as would be expected.

A high degree of association is also evident between the sulphur content of the gluten and the loaf volume. This is confirmed by the highly significant correlation coefficient. This is strong evidence that sulphur, as some component of the protein, contributes in some way to high baking strength.

As is shown in Fig. 2, there is a tendency for the points to be grouped at each end of the regression line.

TABLE V

Results with 1941 Series

SAMPLE	TREATMENT	PROTEIN %	LOAF VOLUME	SULPHUR PERCENT		
				WHEAT	FLOUR	GLUTEN
1	Check	13.4	455	0.14	0.16	0.56
2	Manure	13.5	563	0.12	0.13	0.58
3	Complete	12.5	683	0.18	0.20	0.77
4	Ammonium Sulphate	13.0	693	0.20	0.23	0.71
6	Lime	13.5	438	0.12	0.13	0.52
7	Lime & Phosphate	12.3	440	0.14	0.18	0.57
8	Triple Phosphate	12.4	403	0.14	0.13	0.65
9	Manure & 16 - 20	14.4	713	0.18	0.17	0.74
10	16 - 20	13.5	673	0.17	0.20	0.83
18	Check	13.2	525	0.14	0.17	0.60
19	Ammonium Nitrate	14.1	485	0.13	0.18	0.57
20	Ammonium Nitrate & Gypsum	12.8	750	0.22	0.25	0.75
21	Gypsum	11.6	573	0.20	0.25	0.84

TABLE VI

Correlation Coefficients

<u>Statistic</u>	<u>D. F.</u>	<u>Value</u>
r_{vp}	11	0.116
r_{vw}	11	0.808**
r_{vg}	11	0.742**
r_{pw}	11	-0.337
$r_{vw.p}$	10	0.906**
$R_{v.pw}$	10	0.907**

Note: v - loaf volume; p - protein %;
 w - sulphur in wheat %;
 g - sulphur in gluten %.

* Significant beyond the 5% point
** Significant beyond the 1% point

If the number of samples had been larger, it is highly probable that there would have been more intermediate points. Further, since the soil is naturally deficient in sulphur, there has been greatly increased absorption of sulphur in all cases where it has been applied, and this has been at least partly responsible for the scarcity of intermediate points.

The partial coefficient $r_{vw.p}$ shows a marked increase over the simple r_{vw} , indicating that the elimi-

nation of effect of protein causes an increase in the apparent effect of sulphur on loaf volume.

The multiple correlation coefficient, $R_{v.pw}$ is highly significant. In addition, this multiple is significantly higher, statistically, than either the simple r_{vw} or r_{vp} , which signifies that both protein and sulphur exert a positive influence on loaf volume and that apparent overlapping can be expected.

It is interesting to note that in this material the deposition of sulphur has not, to the slightest degree, followed the deposition of nitrogen, the correlation coefficient actually being negative.

Figure 2

Correlation surfaces showing the relationship between sulphur in wheat and loaf volume and sulphur in gluten and loaf volume. 1941

- New series samples
- Old series samples

Figure 3

Loaf Vol.	455	563	683
Protein %	13.4	13.5	12.5
Sulphur %	0.14	0.12	0.18

Loaf Vol.	693	438	440
Protein %	13.0	13.5	12.3
Sulphur %	0.20	0.12	0.14

Loaf Vol.	403	713	673
Protein %	12.4	14.4	13.5
Sulphur %	0.13	0.18	0.17

Figure 4

Loaf Vol.	485	750
Protein %	14.1	12.8
Sulphur %	0.13	0.22
Loaf Vol.	573	525*
Protein %	11.6	13.2*
Sulphur %	0.20	0.14*

* Values for No.18 Check

1942 Material

Similar analyses were carried out on the 1942 samples. In addition the weights of dry and moist gluten were recorded. The results are presented in Table VII.

The range in loaf volume for this year is not as large as that obtained in 1941, the total range being 207 cc. for this year as compared with 347 for 1941.

Further evidence of the lack of agreement between protein content and loaf volume is evident. There is, however more of a positive relationship here than with the 1941 samples as is shown best by the just significant r_{pv} value, Table VIII.

The association between sulphur content of the wheat and the loaf volume is still apparent, but not to such a high degree as in 1941. If the four samples, 18 to 21, are considered separately, the sulphur is seen to correspond quite well with the loaf volume, and the protein content does not. These four samples are of a different series, as has already been noted. Thus, dividing the data and considering each part separately, a much closer agreement between loaf volume and sulphur in wheat is obtained in both sections, and a lesser agreement between protein and loaf volume. Sample 8 is an outstanding exception, the high loaf volume not being supported by either protein or sulphur content.

TABLE VII

Results for 1942 Series

SAMPLE	TREATMENT	n	PROTEIN %	LOAF VOLUME	SULPHUR PERCENT		WEIGHT OF GLUTEN	
					WHEAT	FLOUR	DRY	WET
1	Check	n	11.2	588	0.13	0.14	4.792	13.68
2	Manure		10.9	573	0.13	0.15	4.434	13.69
3	Complete		10.6	573	0.16	0.14	4.138	12.50
4	Ammonium Sulphate		11.8	708	0.19	0.21	5.155	16.81
6	Lime		12.0	553	0.11	0.12	4.541	12.85
7	Lime & Phosphate		11.2	583	0.12	0.13	4.963	13.82
8	Triple Phosphate		11.3	720	0.12	0.13	5.253	15.39
9	Manure & 16 - 20		11.9	655	0.17	0.18	4.807	14.17
10	16 - 20		11.6	613	0.17	0.18	5.186	14.60
18	Check		12.3	655	0.13	0.14	4.838	14.32
19	Ammonium Nitrate		12.8	640	0.10	0.13	3.964	14.81
20	Ammonium Nitrate & Gypsum		12.8	760	0.19	0.20	5.930	17.52
21	Gypsum		12.1	730	0.18	0.19	5.226	15.17

TABLE VIII
Correlation Coefficients

<u>Statistic</u>	<u>D. F.</u>	<u>Value</u>
r _{vp}	11	0.553*
r _{vw}	11	0.548*
r _{vg}	11	0.027
r _{pw}	11	0.086
r _{dv}	11	0.708**
r _{dp}	11	0.275
r _{dw}	11	0.595*
r _{dg}	11	0.243
r _{mv}	11	0.893**
r _{mp}	11	0.574*
r _{mw}	11	0.527
r _{mg}	11	0.188
r _{vw.p}	10	0.602*
R _{v.pw}	10	0.747**

Note: v - loaf volume; p - protein %;
 w - sulphur in wheat %;
 g - sulphur in gluten %;
 d - wt. dry gluten, gm;
 m - weight moist gluten, gm.

* Significant beyond 5% point
 ** Significant beyond 1% point

There are too few samples in each division to permit statistical calculations and, therefore, the correlation coefficients are derived from all 13 samples.

The partial correlation coefficient $r_{vw.p}$ shows an increase over the simple r_{vw} as would be expected, indicating some improvement in the correlation when the effect of protein is eliminated.

The $R_{v.pw}$ is significantly higher, statistically, than either r_{vw} or r_{vp} , again indicating that both protein and sulphur contribute to the variations in loaf volume.

In the over all correlation between sulphur in gluten and loaf volume, no association is evident between these two variables. Despite this low coefficient, considering the four new series, samples separately shows that the improving effect of higher sulphur in the gluten is definitely present. The irregularities in the old series, however, destroy the correlation.

The range of sulphur content in the gluten is not as great as in 1941, 0.22% as compared with 0.32%. Since loaf volume is also extended over a narrower range, only a few irregularities are necessary to reduce the correlation to below the significant level.

In view of the significant correlation between sulphur in wheat and loaf volume, and also the fact that the sulphur is concentrated in the gluten, it seems justified to conclude that sulphur is still a significant factor affecting the

baking strength of the samples.

In this year's results also, there is no significant correlation between sulphur and nitrogen content.

The weights of dry and moist gluten provide additional information. The highly significant correlation between the weight of moist gluten and loaf volume indicates that the factor responsible for the differences in loaf volume also modifies the physical properties of the moist gluten. The physical properties are obviously not dependent upon protein content alone, possibly not at all. Since sulphur has been shown to be a significant factor contributing to baking strength, there is distinct evidence that the presence of sulphur in larger amounts is at least partly responsible for the improved physical properties of the gluten.

The higher correlation between weight of dry gluten and loaf volume than between protein content and loaf volume is explainable on the basis of purity of the gluten. The more elastic, cohesive and tenacious properties of the better glutens increase the difficulty of complete removal of the starch in gluten washing. Consequently, more of the starch is present in the better glutens at the end of the standardized washing period. Further, this will have a lowering effect on the apparent sulphur content of the gluten.

Figure 5

Correlation surfaces showing the relationship between sulphur in wheat and loaf volume and sulphur in gluten and loaf volume. 1942

- New series samples
- Old series samples

Figure 6

Correlation surface showing the relationship
between the weight of wet gluten and loaf volume.
1942

- New series samples
- Old series samples

Figure 7

Loaf Vol.	588	573	573
Protein %	11.2	10.9	10.6
Sulphur %	0.13	0.13	0.16

Loaf Vol.	708	553	583
Protein %	11.8	12.0	11.2
Sulphur %	0.19	0.11	0.12

Loaf Vol %	720	655	613
Protein %	11.3	11.9	11.6
Sulphur %	0.12	0.17	0.17

1943 Material

The 1943 samples were of very low commercial grade due to extremely unfavourable weather conditions prior to harvest. Many of the samples failed to reach a proper stage of maturity, and all were severely damaged by frost.

Sulphur and protein content of the wheat, together with the baking results are presented in Table IX.

The loaf volume figures show that all of the samples are of uniformly low baking strength. The total range is so low that one value can hardly be considered significantly different from the mean value if the probable baking error is taken into account. Since loaf volume is used as the final basis for the measurement of quality, the material is not suitable for this study, as no quality differences are evident. No statistic involving loaf volume was calculated.

Sulphur analyses of the samples show that considerable variation in sulphur content occurs. The response to the various fertilizers is similar to that of 1941 and 1942. The protein content varies over a normal range but on a slightly lower level.

A notable exception occurs this year, in that there is a highly significant correlation between sulphur and nitrogen content.

TABLE IX

Results for 1943 Series

SAMPLE	TREATMENT	PROTEIN %	LOAF VOLUME	SULPHUR IN WHEAT %
1	Check	10.7	398	0.15
2	Manure	10.6	368	0.18
3	Complete	11.5	310	0.19
4	Ammonium Sulphate	12.1	300	0.19
6	Lime	10.2	398	0.14
7	Lime & Triple Phosphate	10.4	398	0.14
8	Triple Phosphate	10.0	358	0.14
9	16 - 20 & Manure	11.7	325	0.16
10	16 - 20	11.9	340	0.17
18	Check	11.1	428	0.16
19	Ammonium Nitrate	11.3	445	0.13
20	Ammonium Nitrate & Gypsum	12.5	455	0.23
21	Gypsum	12.2	418	0.25

Cystine Analyses

On the assumption that most of the sulphur is present in the gluten in the form of one or both of the two common sulphur-containing amino acids, cystine and methionine, a quantitative measurement of each of these in the gluten was attempted. Only the measurement of cystine was sufficiently successful to warrant reporting the results. The analyses were carried out on the 1941 and 1942 samples after they had been bulked according to special grouping as indicated in "Materials". Protein content of the gluten was also determined after the samples had been bulked.

The values for sulphur in wheat, sulphur in gluten, and loaf volume are the mean values of those samples which were bulked to produce the new sample. It is expected that these values will approximate what would have been obtained by performing the analysis or baking test in each case. The data are presented in Table X.

The amount of cystine in the gluten ranges from 1.40% to 2.29%. The cystine sulphur represents from 56% to 89% of the total sulphur with a mean value of 76%. Subject to error of the method, it appears that cystine is the main sulphur containing component of the gluten protein.

The cystine percentage in the gluten is also positively and significantly correlated with loaf volume.

TABLE X

Relation of cystine results to those previously discussed

SAMPLE	LOAF VOLUME	TOTAL S. in GLUTEN %	CYSTINE %	CYSTINE S. in GLUTEN %	RATIO Cystine S. Total S.	TOTAL S. in WHEAT	PROTEIN in GLUTEN %
<u>1941</u>							
1	563	0.58	1.74	0.46	0.79	0.120	65.9
2	691	0.76	2.13	0.56	0.74	0.183	65.3
3	427	0.58	1.40	0.37	0.64	0.133	75.3
4	525	0.60	1.99	0.53	0.88	0.140	64.0
5	505	0.58	1.91	0.51	0.89	0.135	59.7
6	573	0.84	2.27	0.60	0.71	0.200	60.5
<u>1942</u>							
1	580	0.72	1.52	0.40	0.56	0.130	51.1
2	659	0.73	2.29	0.61	0.83	0.176	58.8
3	568	0.58	1.48	0.39	0.67	0.115	55.4
4	648	0.57	1.82	0.49	0.85	0.115	56.6
5	760	0.73	2.15	0.57	0.78	0.190	50.8
6	730	0.63	1.94	0.52	0.82	0.180	56.2

TABLE XI

Correlation of Cystine % with other Variables

<u>Statistic</u>	<u>D. F.</u>	<u>Value</u>
r_{cv}	10	0.557*
r_{cg}	10	0.640*
r_{cw}	10	0.749**

Note: c - cystine %; v - loaf volume, cc.
g - sulphur in gluten %;
w - sulphur in wheat %.

* Significant

** Highly Significant

There is a tendency for the cystine-sulphur/total-sulphur ratio in the gluten of 1942 series to be high in those samples exhibiting high baking strength, and low in those of inferior baking strength, but this is not borne out by 1941 results.

The cystine content of the gluten is highly significantly correlated with the sulphur content of the whole wheat. Since in both 1941 and 1942 a close relationship was apparent between sulphur in whole wheat and loaf volume, and since the cystine content of the gluten corresponds very well with the sulphur content of the wheat, it seems definite that the cystine in the wheat or gluten

contributes to baking strength.

The nitrogen content of the gluten shows that all the glutes are not of the same degree of purity. There is a tendency for higher purity of gluten to be associated with low baking strength. Sample 3, with the lowest loaf volume, has the lowest cystine value and the highest gluten purity. In direct contrast, Sample II has the highest loaf volume, one of the highest cystine contents, and the lowest gluten purity. This is further evidence that sulphur, probably in the form of cystine, improves the physical properties of the gluten. It also indicates that if the samples were all of the same degree of purity, a greater range would exist between the high and low cystine, or sulphur in gluten, values.

DISCUSSION

It would appear that sulphur has heretofore been overlooked as a possible factor affecting baking strength of wheat. No publication has been located in which this problem has been discussed.

The first indication that sulphur might be a factor in wheat quality arose from the fertilizer experiments of Wyatt, Newton and Ignatieff (26). It was apparent that an improvement in baking quality generally resulted from the application of sulphur fertilizers. No attempt was made, however, to correlate the sulphur content of the wheat or wheat fractions with the baking strength.

Peters (17) found that the application of sulphur fertilizers resulted in increased sulphur content of the wheat but he did not associate the sulphur content of the wheat with improved baking quality. In this, and the preceding paper, the subject is dealt with from the aspect of plant nutrition.

This material is well suited to this study for several reasons:

- (1) It provides a wide range of quality, as evidenced by the baking results.
- (2) There is considerable range in protein content and for the most part the expected relationship between protein content and loaf volume does not occur.

- (3) The wheat has been produced on a soil naturally deficient in sulphur and hence there has been a marked increase in sulphur deposition wherever sulphur-containing fertilizers have been applied.
- (4) In this systematic longtime study of the fertilizer requirements of the gray wooded soils, yearly variations in the significance of quality factors in the wheat can be studied.

Perhaps this particular set of conditions has not occurred in any other part of the wheat growing areas of North America. It may also be, however, that this phenomenon is purely a result of the specific conditions and will not explain protein quality differences under other conditions. At least, however, this does represent one case where a chemical difference in constitution has been closely associated with varying quality in wheat protein.

There is need for much further research on this problem. It would be of considerable significance if the amount of sulphur or sulphur-containing amino acids in the protein could be shown to account for variations in wheat protein quality in general.

Greaves and Bracken (11), have shown that the sulphur content of wheat differs between varieties. They further state that the sulphur/nitrogen ratio remained quite constant. The foregoing results have shown that the latter

is not true in all cases.

Csonka (7) has shown that the percentage of cystine is considerably higher in the protein of Marquis in Ohio than it is in the protein of Tenmarq or Fulhio, the former being hard red spring variety, and the latter two, hard red winter and soft winter respectively.

A study of the amounts of sulphur and sulphur-containing amino acids in the wheat fractions, particularly the protein, among varieties, and perhaps kinds, might reveal the reason for protein quality differences. In Western Canada the quality of the protein of Garnet has been proven to be inferior for bread making to that of the approved hard red spring varieties. It would be interesting to determine whether or not the lower quality is associated with lower sulphur and cystine content. One of the main difficulties probably would be encountered in obtaining samples of different varieties of comparable protein content, grown under similar conditions, but differing sufficiently in protein quality as indicated by the baking results.

While significant information has been obtained in this study using crude gluten as representative of the protein, more precise results could be obtained using a more purified protein. As was illustrated, the weak glutens are purer than the stronger glutens when obtained under constant washing conditions. This could be partially overcome by

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prolonged washing, but even then differences in purity would likely occur.

Further investigation of methods for the accurate determination of the sulphur-containing amino acids in both the wheat and the protein would be of value in continued studies of the influence of sulphur on baking strength.

The manner by which an increased amount of the sulphur-containing amino acids could influence the gluten properties and also protein structure, assuming that the two are related, reaches further into the complexity of protein chemistry than this discussion is prepared to venture. However, it is of interest to note that Hoffman and Gortner (14) state that aside from the normal peptide linkage, only one other linkage has been demonstrated in proteins and that is the S-S linkage in cystine.

SUMMARY AND CONCLUSIONS

(1) The purpose of this investigation has been to examine the possibility of sulphur being a factor affecting the baking strength of wheat. The samples used were produced on the Breton Field Experiment where improved baking strength, not explainable on the basis of protein content, had been noted as a result of the application of sulphur-containing fertilizers.

(2) Three years' material have been studied. Protein content, sulphur content and loaf volume were determined in the three years, sulphur in flour and sulphur in gluten in two years, and the weights of moist and dry gluten in one. The data were analysed statistically.

(3) Methods for the determination of cystine and methionine have been discussed. A gasometric method for the determination of cystine in the gluten has been applied to some combined 1941 and 1942 samples and the results correlated with loaf volume, sulphur in wheat and sulphur in gluten.

(4) The protein content in this material is not adequate as an indicator of baking strength.

(5) Sulphur content of the wheat is positively and significantly correlated with loaf volume. The relationship

CHAPTER IV

- (1) The purpose of this chapter is to provide a general outline of the principles and methods of the study of the history of the world, and to show how these principles and methods are applied in the study of the history of the world.
- (2) The purpose of this chapter is to provide a general outline of the principles and methods of the study of the history of the world, and to show how these principles and methods are applied in the study of the history of the world.
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- (8) The purpose of this chapter is to provide a general outline of the principles and methods of the study of the history of the world, and to show how these principles and methods are applied in the study of the history of the world.
- (9) The purpose of this chapter is to provide a general outline of the principles and methods of the study of the history of the world, and to show how these principles and methods are applied in the study of the history of the world.
- (10) The purpose of this chapter is to provide a general outline of the principles and methods of the study of the history of the world, and to show how these principles and methods are applied in the study of the history of the world.

varies between years, being more outstanding when protein is less closely associated with baking strength and when loaf volume differences are large.

(6) The sulphur in wheat is concentrated in the gluten. It is present in larger amounts in the glutens from the "strong" flours and it appears to modify the physical properties of the gluten, increasing elastic, cohesive and extensible characteristics. The weight of wet gluten is highly correlated with loaf volume.

(7) Cystine is the principal form of sulphur in gluten, ranging from 56% to 89% with a mean value of 76%. There is a tendency for the cystine-sulphur/total-sulphur ratio to be higher in the "strong" samples. Most of the sulphur not accounted for as cystine is probably present as methionine.

(8) Cystine content of the gluten is closely associated with loaf volume, sulphur in gluten, and particularly sulphur in wheat.

(9) The sulphur/nitrogen ratio in wheat is not necessarily constant.

ACKNOWLEDGMENTS

The writer wishes to express his sincere thanks to Dr. A. G. McCalla, under whose direction this work has been carried out, for his helpful suggestions and criticisms during the course of this investigation, and for the critical reading of this paper; to Dr. F. A. Wyatt of the Department of Soils of this University, for his courtesy in furnishing the material for this study and the baking photographs; to Mr. G. M. Tosh, Technician, for his valuable services in apparatus construction, drafting and photography; and to the National Research Council for financial assistance.

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18.	1. The first part of the report is devoted to a general survey of the situation in the country.
19.	2. The second part of the report is devoted to a detailed analysis of the economic situation.
20.	3. The third part of the report is devoted to a detailed analysis of the social situation.
21.	4. The fourth part of the report is devoted to a detailed analysis of the political situation.
22.	5. The fifth part of the report is devoted to a detailed analysis of the cultural situation.
23.	6. The sixth part of the report is devoted to a detailed analysis of the environmental situation.
24.	7. The seventh part of the report is devoted to a detailed analysis of the international situation.
25.	8. The eighth part of the report is devoted to a detailed analysis of the future prospects.
26.	9. The ninth part of the report is devoted to a detailed analysis of the conclusions.
27.	10. The tenth part of the report is devoted to a detailed analysis of the recommendations.

APPENDIX

FOREWORD

The data presented in this appendix are not associated with the foregoing thesis.

Since wartime labour regulations curtailed research in non-essential projects, the "Sulphur and Wheat Quality" investigation was interrupted. This report represents some work done in connection with the investigation into the production of 2,3-butylene glycol from grain, carried on in associated laboratories. It is included in this appendix only for the purpose of a permanent record.

INTRODUCTION

Information with respect to the program of the investigation and the organism used in the fermentation are found in Canadian Investigations on the Production and Esterification of 2,3-Butylene Glycol (6), and Studies on the production of 2,3-Butylene Glycol from Grain (22).

The starch analyses presented in the following report were carried out in order to determine whether or not a relationship existed between the yield of glycol and the percentage of starch in the wheat samples used in the fermentations.

MATERIAL

Representative grade samples of wheat were collected from five inspection offices, Calgary, Edmonton, Moose Jaw, Saskatoon and Winnipeg. The commercial grade and the origin of each sample are indicated in Table I-A along with the other data.

Comparable pairs of samples, one weathered and one unweathered, from four points in Alberta were analysed to determine starch content differences due to weathering and the relation of such differences to glycol yields. Details are presented with the results, Table II-A.

METHOD

Starch was determined using Clendenning's modification of the Mannich-Lenz method (6). Starch percent is expressed on a moisture free basis.

TABLE I - A
Grade Samples

SAMPLE	PROTEIN %	STARCH %	GLYCOL YIELD %		
			42(2)* 8% Mash	47(2)* 8% Mash	47(2)* 15% Mash
S 1	13.5	65.8	0.91	1.24	1.77
S 2	12.4	63.5	0.99	1.24	1.86
S 3	11.7	62.4	1.11	1.11	1.92
S 4	11.5	63.4	1.06	1.20	1.98
S 5	11.8	63.5	0.98	1.25	1.92
S 6	11.8	60.8	1.04	1.16	1.95
S Feed	11.8	62.1	1.03	1.25	1.99
E 1	11.6	60.7	1.00	1.33	1.97
E 2	11.8	64.0	0.98	1.28	1.85
E 3	11.6	63.7	1.03	1.23	1.99
E 4	11.6	66.8	1.00	1.10	1.97
W 1	13.5	58.7	0.98	1.10	1.77
W 2	12.4	61.6	1.04	1.24	1.74
W 3	12.4	63.4	0.97	1.21	1.81
W 4	12.0	60.1	1.00	1.09	1.92
W 5	12.0	63.1	0.99	1.17	1.93
W 6	11.3	57.7	0.98	1.24	1.79
C 1	13.8	61.6	1.00	1.22	1.81
C 2	12.8	61.6	1.04	1.20	1.78
C 3	12.0	64.9	0.93	1.14	1.87
C 4	11.8	65.5	1.04	1.16	1.92
C 5	11.5	65.2	0.93	1.17	1.89
M 2	13.4	59.3	0.98	1.23	1.86
M 3	12.8	61.6	0.98	1.22	1.89

* Refers to number of the organism

S = Saskatoon; E = Edmonton; W = Winnipeg; C = Calgary;

M = Moose Jaw.

U. S. GEOLOGICAL SURVEY

WATER RESOURCES DIVISION

REPORT OF INVESTIGATION

State	County	Section	Sub-section	Area	Notes
Ill.	Adams	1	1	1.00	1.00
Ill.	Adams	1	2	1.00	1.00
Ill.	Adams	1	3	1.00	1.00
Ill.	Adams	1	4	1.00	1.00
Ill.	Adams	1	5	1.00	1.00
Ill.	Adams	1	6	1.00	1.00
Ill.	Adams	1	7	1.00	1.00
Ill.	Adams	1	8	1.00	1.00
Ill.	Adams	1	9	1.00	1.00
Ill.	Adams	1	10	1.00	1.00
Ill.	Adams	1	11	1.00	1.00
Ill.	Adams	1	12	1.00	1.00
Ill.	Adams	1	13	1.00	1.00
Ill.	Adams	1	14	1.00	1.00
Ill.	Adams	1	15	1.00	1.00
Ill.	Adams	1	16	1.00	1.00
Ill.	Adams	1	17	1.00	1.00
Ill.	Adams	1	18	1.00	1.00
Ill.	Adams	1	19	1.00	1.00
Ill.	Adams	1	20	1.00	1.00
Ill.	Adams	1	21	1.00	1.00
Ill.	Adams	1	22	1.00	1.00
Ill.	Adams	1	23	1.00	1.00
Ill.	Adams	1	24	1.00	1.00
Ill.	Adams	1	25	1.00	1.00
Ill.	Adams	1	26	1.00	1.00
Ill.	Adams	1	27	1.00	1.00
Ill.	Adams	1	28	1.00	1.00
Ill.	Adams	1	29	1.00	1.00
Ill.	Adams	1	30	1.00	1.00
Ill.	Adams	1	31	1.00	1.00
Ill.	Adams	1	32	1.00	1.00
Ill.	Adams	1	33	1.00	1.00
Ill.	Adams	1	34	1.00	1.00
Ill.	Adams	1	35	1.00	1.00
Ill.	Adams	1	36	1.00	1.00
Ill.	Adams	1	37	1.00	1.00
Ill.	Adams	1	38	1.00	1.00
Ill.	Adams	1	39	1.00	1.00
Ill.	Adams	1	40	1.00	1.00
Ill.	Adams	1	41	1.00	1.00
Ill.	Adams	1	42	1.00	1.00
Ill.	Adams	1	43	1.00	1.00
Ill.	Adams	1	44	1.00	1.00
Ill.	Adams	1	45	1.00	1.00
Ill.	Adams	1	46	1.00	1.00
Ill.	Adams	1	47	1.00	1.00
Ill.	Adams	1	48	1.00	1.00
Ill.	Adams	1	49	1.00	1.00
Ill.	Adams	1	50	1.00	1.00
Ill.	Adams	1	51	1.00	1.00
Ill.	Adams	1	52	1.00	1.00
Ill.	Adams	1	53	1.00	1.00
Ill.	Adams	1	54	1.00	1.00
Ill.	Adams	1	55	1.00	1.00
Ill.	Adams	1	56	1.00	1.00
Ill.	Adams	1	57	1.00	1.00
Ill.	Adams	1	58	1.00	1.00
Ill.	Adams	1	59	1.00	1.00
Ill.	Adams	1	60	1.00	1.00
Ill.	Adams	1	61	1.00	1.00
Ill.	Adams	1	62	1.00	1.00
Ill.	Adams	1	63	1.00	1.00
Ill.	Adams	1	64	1.00	1.00
Ill.	Adams	1	65	1.00	1.00
Ill.	Adams	1	66	1.00	1.00
Ill.	Adams	1	67	1.00	1.00
Ill.	Adams	1	68	1.00	1.00
Ill.	Adams	1	69	1.00	1.00
Ill.	Adams	1	70	1.00	1.00
Ill.	Adams	1	71	1.00	1.00
Ill.	Adams	1	72	1.00	1.00
Ill.	Adams	1	73	1.00	1.00
Ill.	Adams	1	74	1.00	1.00
Ill.	Adams	1	75	1.00	1.00
Ill.	Adams	1	76	1.00	1.00
Ill.	Adams	1	77	1.00	1.00
Ill.	Adams	1	78	1.00	1.00
Ill.	Adams	1	79	1.00	1.00
Ill.	Adams	1	80	1.00	1.00
Ill.	Adams	1	81	1.00	1.00
Ill.	Adams	1	82	1.00	1.00
Ill.	Adams	1	83	1.00	1.00
Ill.	Adams	1	84	1.00	1.00
Ill.	Adams	1	85	1.00	1.00
Ill.	Adams	1	86	1.00	1.00
Ill.	Adams	1	87	1.00	1.00
Ill.	Adams	1	88	1.00	1.00
Ill.	Adams	1	89	1.00	1.00
Ill.	Adams	1	90	1.00	1.00
Ill.	Adams	1	91	1.00	1.00
Ill.	Adams	1	92	1.00	1.00
Ill.	Adams	1	93	1.00	1.00
Ill.	Adams	1	94	1.00	1.00
Ill.	Adams	1	95	1.00	1.00
Ill.	Adams	1	96	1.00	1.00
Ill.	Adams	1	97	1.00	1.00
Ill.	Adams	1	98	1.00	1.00
Ill.	Adams	1	99	1.00	1.00
Ill.	Adams	1	100	1.00	1.00

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CONCLUSION

No consistent relationship is apparent between starch content and glycol yield. Statistical analyses of the starch content with the glycol yield for the 15% mash shows a correlation coefficient of 0.260, not significant.

The starch content is negatively and highly significantly correlated with protein content, a coefficient of -0.707 being obtained.

TABLE II - A

Weathered Wheat Samples

SAMPLE	GRADE	ORIGIN	DATE THRESHED	STARCH %	GLYCOL YIELD %		
					42(2)	47(2)	500*
8	#5	Holden	Fall 1942	59.7	-	2.01	1.94
7	#6	Holden	Spring 1943	58.3	-	2.08	1.82
13	40	Wainwright	Fall 1942	63.4	2.14	2.20	2.02
14	#5	Wainwright	Spring 1943	63.7	2.14	2.31	1.89
17	#5	Vegreville	Fall 1942	59.8	2.08	2.09	1.89
18	#6	Vegreville	Spring 1943	61.7	2.10	2.05	1.83
30	#5	Bentley	Fall 1942	60.6	2.12	2.15	1.93
31	#6	Bentley	Spring 1943	62.2	1.97	1.96	1.88

* Refers to number of the organism.

CONCLUSION

Starch content tends to be higher in the weathered sample from each pair. However, the increase is not consistent and ranges from -1.4% to +1.9%. There is no significant relationship between starch and glycol except perhaps with organism 500 where a negative relationship appears to exist.

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