IOWA STATE UNIVERSITY
Digital Repository

Retrospective Theses and Dissertations

Iowa State University Capstones, Theses and Dissertations

1923

A study of the properties of wheat starch with reference to the baking qualities of flour

Glenn Garnet Naudain
Iowa State College

Follow this and additional works at: https://lib.dr.iastate.edu/rtd

Part of the Agriculture Commons, and the Food Science Commons

Recommended Citation

Naudain, Glenn Garnet, "A study of the properties of wheat starch with reference to the baking qualities of flour " (1923). *Retrospective Theses and Dissertations*. 14260.
https://lib.dr.iastate.edu/rtd/14260

This Dissertation is brought to you for free and open access by the Iowa State University Capstones, Theses and Dissertations at Iowa State University Digital Repository. It has been accepted for inclusion in Retrospective Theses and Dissertations by an authorized administrator of Iowa State University Digital Repository. For more information, please contact digirep@iastate.edu.

المنارة للاستشارات

www.manaraa.com

DP

14507

INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps.

ProQuest Information and Learning
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
800-521-0600

UMI®

NOTE TO USERS

This reproduction is the best copy available.

UMI®

A STUDY OF THE PROPERTIES OF WHEAT STARCH WITH REFERENCE TO THE BAKING QUALITIES OF FLOUR

by

Glenn Garnet Naudain

A Thesis Submitted to the Graduate Faculty
for the Degree of
Doctor of Philosophy
No. 14
Major subject (Food Chemistry)

Approved

Signature was redacted for privacy.

In charge of Major Work

Signature was redacted for privacy.

Head of Major Department

Signature was redacted for privacy.

Graduate Dean

Iowa State College
1923.

UMI Number: DP14507

UMI®

UMI Microform DP14507

Copyright 2006 by ProQuest Information and Learning Company.
All rights reserved. This microform edition is protected against
unauthorized copying under Title 17, United States Code.

ProQuest Information and Learning Company
300 North Zeeb Road
P.O. Box 1346
Ann Arbor, MI 48106-1346

TX558.W5
N22s

T875

I N D E X

A STUDY OF THE PROPERTIES OF WHEAT STARCH WITH

REFERENCE TO THE BAKING QUALITIES

OF FLOUR.

INDEX (Continued).

INDEX (Continued)

A STUDY OF THE PROPERTIES OF WHEAT STARCH WITH REFERENCE TO THE BAKING QUALITIES OF FLOUR.

INTRODUCTION.

Previous attempts to establish a possible relationship between the constituents of wheat flour and flour strength have met with little success. In the attempt to establish this relationship, a review of the work given in the literature on flours and a short review on starches will be given. Following this review there will be presented the data resulting from the experiments which have been made in the attempt to carry forward the work of previous investigators in this field.

In the literature of this subject the following investigators have reached the conclusions indicated below.

Olson [74], in his Wheat and Flour investigations, brings the research up to the year 1917. He points out the following facts:

I. The quality of a flour and the volume of a loaf have no relation to the nitrogen content.

II. The quality of a flour and the volume of a loaf have no relation to the alcohol soluble nitrogen.

III. There is no definite relation between the volume of loaf and the total ash.

IV. There is no definite relation between total amount of gluten and the volume producing capacity.

V. The water soluble solids do not show any relation to the volume producing capacity.

VI. It is impossible from the data to obtain or establish a relation between acidity and the volume of the loaf.

VII. The nitrogen-free and ash-free extract do not show the relation to the volume of the loaf that would be expected.

VIII. Wood's ratio of soluble ash to the total nitrogen determination contains irregularities.

IX. There is no relation between the gluten and its water-containing property.

X. The removal of the alcohol extracts impairs the baking quality and makes it impossible to obtain satisfactory fermentation.

XI. Dialysis removes the soluble salts and gives unsatisfactory fermentation.

Jago [54] shows that a strong flour must have a sufficiency of sugar for fermentation. He also states that excessive moisture content, above thirteen per cent, has a tendency to induce fermentation changes in flour.

Chapman [23] shows that the immersion refractometer has no value in the determination of the ash content of flour. The ash content of a flour cannot be predicted from the refractometer reading.

Jago [54] states that the ash helps to establish the commercial grade of a flour. Potents seldom contain more than one half of one per cent of ash. Straights rarely run over 0.55 per cent ash. Clears will average from 0.8 to 1.75 per cent ash.

Jago [54] believes the most satisfactory content of nitrogen in flour to be from 1.8 to 2.1 per cent. The presence of a high percentage or a low percentage of nitrogen is not desirable.

Upson [97] states that the presence of salts and acids in flour affects the quality of the gluten.

Hawks [50] finds that the presence of ammonium nitrate to the extent of 0.1 to 0.2 per cent by weight is advantageous in the making of bread. The addition to dough batches of ammonium persulphate in quantities of less than 0.019 per cent by weight during the latter stages of fermentation and baking, produces a detrimental effect.

Jago [54] shows that color in flour indicates the quality of the flour.

Gortner [43] and his coworkers have developed the action of various reagonts upon gluten. They conclude that a flour which owes its inferior strength to the quality of its gluten is weak because of the fact that its gluten possesses markedly inferior colloidal properties and is not as perfect a colloidal gel as is the gluten of a strong flour.

Buchanan and Naudain [20] develop the influence which the size of the starch grains has upon the loaf. The influence [68] of temperature upon the starch is also given.

Collatz [27] deals in his paper with the effects of diastatic ferments upon the strength of wheat flours. He concludes that the strong flours show a higher sugar content and greater diastatic activity than do the weaker flours.

Rumsey [82] determined the effects of diastatic enzymes of the wheat flour in panary fermentation, with respect to concentration, time, temperature, acidity, and diastatic power. He concludes that the flour showing the greatest diastatic power should show the greatest strength and consequently the greatest baking value, provided the relative quality and quantity of the gluten are the same.

With the preceding facts as a background, the study of the effect of the size, reagents, and temperature on the starch grains in flour can be understood. Little work has been done in this field. Many have held the opinion that starch is without any marked effect in flour. Armstrong [3] reports that the size of the grains of starch affects the rate of sugar formation in that the larger grains are converted into sugar earlier than the smaller grains. Whymper states that the large granules are attacked before the smaller granules in producing sugar. Jago [26] examined the relation of size of starch grains to size of loaf by mixing first, the large granules of potato starch, and then the smaller granules of maize starch with wheat flour. He found that the maize starch gave the larger loaf and the potato starch the smaller.

The following is a statement of some of the more detailed chemical and physical properties of wheat starch.

I. The empirical formula [61] of starch is $n(C_6 H_{10} O_5)_x$. On account of such a formula, there may be large numbers of isomers [79], depending upon the deposition, temperature, sunlight, reagents present, etc.

II. Starch is non-volatile and generally amorphous.

III. It is insoluble in alcohol.

IV. It is for the most part insoluble in cold water, but soluble in hot water. The solution in which water and starch are combined causes a marked rotation on polarised light.

V. In Woodman's [103] opinion starch is neutral in reaction and forms few known definite compounds; its chemical affinities are small and therefore it is difficult to obtain in a pure state.

VI. None of the members reduce Fehling's Solution.

VII. Starch, treated by acid, undergoes hydrolysis, yielding sugars, if the process is carried to completion, otherwise dextrines.

VIII. Starch [I] is insoluble in Schweitzer's solution, and is precipitated by tannin and ammoniacal lead-acetate.

IX. Starch is very hygroscopic, and contains much water even when dried in a vacuum.

X. There has been much disagreement concerning the temperature at which gelatinization takes place.

The gelatinization temperature of wheat starch is given by

Parou, Elbrodt, and Newmann at 80°C. Francis and Smith [40] state that this temperature for wheat starch is 66°C. They found that the point at which gelatinization takes place depends on the rate of heating. They assumed that the gelatinization temperature was reached at the point where optical activity disappeared. Greenish [45] places the gelatinization temperature of wheat starch at 65°C. Nyman [71] affirms that it is 59°C. Dox and Roark [30] state that different varieties of the same kind of starch require different gelatinization temperatures.

XI. Soluble starch is produced by boiling starch with water; the solution thus obtained can be clarified by the addition of a little caustic alkali. Soluble starch is the first product of the action of dilute acids or ferments on starch; it is a very perfect colloid possessing a high viscosity. Soluble starch may be prepared by various other methods[79].

XII. Fernbach [32] states that ~~the microscope~~ provides the best instrument for the detection of starch especially when the microscope is aided by an iodine solution.

XIII. The quantity of starch is estimated by hydrolysis to glucose and it is then determined in the usual manner.

XIV. Sameo [83] states that the molecular weight of natural starch is one hundred thousand.

XV. The structure of the starch grains can be seen by the use of the microscope. The points which should be sought for in the microscopic observation of starches are the following: the shape and size of the granules, the character and position of the hilum, their concentric markings, and their appearance under polarized light.[100]

XVI. Kramer [58] states that starch granules possess a concentrically stratified structure. These stratifications have caused several theories to be advanced. First, they were thot to be granulose and amylo-cellulose, and to be different chemical compounds. Later, the idea has been accepted that the striations are due to different densities in the starch, and that the exterior and interior of the starch grain differ in their water of hydration.

XVII. The young grains of starch are spherical; the older ones are ovoid or polygonal. Winton [100] further states that wheat starch granules are, for the most part, round; the hilum is in the center and has very faint concentric rings. The wheat granules are in two sizes, the large ones from 12 to 50 microns in diameter and the smaller ones from 3 to 9 microns.

Investigation has revealed the following conclusions regarding the relation of starch to bread:

Temperature increases the size of starch granules when placed in water solution. An increase in temperature also increases the viscosity of the solution. These factors affect the colloidal properties of the solutions. The colloidal properties, the viscosity, and the swelling of the starch grains have a large influence on the baking quality of the flour and on the size of the resulting loaf.

A possible relationship [20] between the starch of wheat flour and flour strength has been suggested by various investigators. Armstrong [3] indicates a variation in size of the starch grains of wheat flour. Baking tests indicate a slight advantage in flavor of the starches having the smaller starch grains. Hardy makes this statement: "The power of dough to retain its shape may be due,in some cases, primarily to the nature and number of starch grains." Snyder [89] believes starch to be without effect in influencing the baking strength. The more recent work of Rumsey [82] shows the value of diastatic enzymes in flour. Collatz [27] in his study of the effect of addition of diastatic enzymes, concludes that the starch of strong flour is more easily hydrolyzed than that of weak flour.

It is evident that that the literature of the subject does not give a very definite idea of the importance of starch with regard to strength of flour.

Upson and Calvin [97], Gortner and Doherty [42], and Sharp and Gortner [43], have shown the necessity for a consideration of the colloidal properties of gluten. It was with the idea of determining what the colloidal properties of starch might indicate with respect to flour that this research problem was undertaken.

EXPERIMENTAL.

With the literature summarized above as a background, the present investigations have been undertaken. They cover, as indicated in the beginning of this paper, a microscopic, viscosity and an imbibitional study of the effect of heat and various reagents on wheat starch and flour. The microscopic data shows the effect of temperature on the size and gelatinization of the starch grains. The sizes given are the average resulting from one to two hundred measurements. The measurements were made under the high power of the microscope and the scale was calibrated to read in microns. The measurements were easily, rapidly and accurately taken and the experimental error will not be greater than one micron.

The first table [68] shows the effect of time and temperature upon the swelling and gelatinization of starch. One half of a gram of wheat starch to one hundred cubic centimeters of distilled water was used in each of the runs.

		30°			35°			40°
Time Minutes	Large Grains	Small Grains	Gelatinization	Large	Small	Gelatinization	Large	Small
0	20.8	5.0						
5	21.6	4.5	None	21.6	4.5	None	23.6	4.5
10	21.7	4.7					23.3	4.9
15	22.1	4.8					23.6	4.9
20	22	4.6					---	---
25	---	---					---	---
30	22	4.7					24.0	4.9
40								
50								
60								
70								
80								
90								

Table I.

Pure Wheat St

	45°			50°				55°		
			Gelatin-			Gelatin-	Time			Gelatin-
el.--	Large	Small	ization--	Large	Small	ization--	Minutes	Large	Small	ization
							5	31	5.6	30%
5%	24.9	4.6	10%	26.5	4.8	20%	10			
				26.6	6		15			
				35.8	6		20			
				38.2	6.4		30			
				---	---		40			
				38.1	7.2		50			
				40.5	8.0	50%	60			
				40.0	8.7	60%	80			
				39.8	9.6		100			
				41.7	9.6		120			
				38.2	9.5		140			
				37.7	9.3	66%	160			
							180			
							200			
							220			
							240			

rch

	60°			65°			70°			75°
arge	Small	Gelatin-ization--	Large	Small	Gelatin-ization--	Large	Small	Gelatin-ization--	Large	Small
35.8	6.5	40%	38.8	7.7	55%	40.8	8.4	80%	41.1	8.6
38.9	7.9					42.7	8.4	90%		
40.8	7.9	45%				43.7	9.9			
42.9	8.6	60%				43.2	9.8			
---	---					43.9	10.2	90%		
42.3	8.7					39.6	10.0			
---	---					36.9	10.1	99%		
41.6	8.7					36.2	10.0			
40.9	8.9									
39.9	8.9									
39.1	9.4									
38.5	9.4									
39.6	9.6									
39.6	9.9									
39.5	10.0									
38.2	10.0	90%								
39.3	10.1									

latin- ation--	Time Min.	80° Large	Small	Gelatin- ization--	85° Large	Small	Gelatin- ization	90° Large	Small	Gelatin ization
5%	5	43.7	11.4	99%	45.5	13	All	---	---	All
	10	40.7	11.5							
	15	38.6	11.1							
	20	36.9	10.5							
	30	32.2	10.5	99%						
	40									

Starch grains heated with CO_2 free H_2O.

Time Min.	Large	Small---	Large	Small---	Large	Small
10	27.5	6	37.1	7.9	42.1	8.4

The table indicates that with the increase in temperature there is a related increase in the size of the starch grains. It gives the percentage of the starch gelatinization which occurs at various lengths of time and various temperatures. At 90°C the starch granules were gelatinized entirely out of shape and very little material was visible.

The effect which was produced by the water free from CO_2 upon the starch grains is shown in the table labelled, "Starch grains heated with CO_2 free H_2O." The table shows that the presence of CO_2 does not materially affect the size of the starch grains.

The effect of heat on the starch grain in the loaf was determined [68]. It is apparent that the gelatinization in the loaf at baking temperature influences the size of the loaf.

The size of the starch grains and the gelatinization of starch in the baked loaf were examined. Samples were taken at the surface of the loaf, directly under the crust, one-half an inch within the loaf and from the middle of the loaf.

Table II.

Sample Location	Starch grain size	Starch grain Gelatinized.
Surface Crust	26.6 microns	40%
Right under crust	28.5 "	40%
In one-half inch	25.7 "	33%
Starch in center	23.4 "	30%

The temperature of a baking loaf was determined. The temperature of the oven varied from 195°C at the beginning, to 205°C at the end. The thermometers were insulated in glass tubes, with corks at the ends of the glass tubes to hold the thermometers. Three thermometers were used. One was placed immediately under the crust on one side of the loaf. Another was placed in the dough one inch from the end of the loaf. The third was enclosed in the center of the loaf.

The following data [68] were obtained:

Table III.

Min. in oven	Side Thermometer	End Thermometer	Center Thermometer.
3	68	28	28
10	95	36	34
15	98	46	46
17	98	54	53
20	103	66	67
25	104	78	78
30	110	94	92
35	111	96	95
40	115	98	97
43	118	99	98
48	121	99.5	98.5
50	120	99.5	98.5
54	120	99.5	98.8
56	119	98.5	98.8

Bread is ordinarily in the oven from thirty to forty minutes. This means the starch in the loaf is not subjected to a temperature above 95°C. Considering the inhibitory action of other substances on the starch gelatinization and the low percentage of water, the resulting forty per cent of gelatinization of the starch which occurred is reasonable. The higher temperature which prevails at the surface of the loaf changes the starch to dextrin.

The gelatinization temperature of wheat starch resulting from experimentation was found to be 68°C. The indentation or break in the starch wall was taken as the point at which the gelatinization begins to take place, and the temperature at this point is considered to be the gelatinization temperature.

There would be less swelling and gelatinization within the loaf than would result in free starch in large amounts of water. There was, however, throughout the loaf, a marked increase in the size of the starch grains, and a large percentage of the grains were gelatinized. There was more swelling of the grains under the crust than in it. This fact is accounted for by the low percentage of water within the crust.

The ratio of large starch grains to small starch grains should have an influence on the starch colloidal properties. It was found that the large starch grains started to gelatinize before the small grains. At higher temperatures, there were traces of the large starch grains left while the smaller starch grains had disappeared earlier.

Table IV [68] represents this. The ratio of large starch grains to small starch grains is used. The time required in minutes to accomplish the changes and the temperature employed, are given.

Table IV.

in tes	30°	35°	40°	45°	50°	55°	60°	65°	70°	80°
[illegible]	50-148	17-52	30-84	20-62	25-83	17-57	11-37	15-48	16-44	19-23
0	20-64		15-48	---	6-18		28-100			
5	16-54		11-32	---	8-24		8-26			

(Temperatures)

The gelatinization of the large and small starch grains in baking is influenced by various reagents. A study of this influence was made outside of the loaf by means of separate reagents. The effects of the reagents on the wheat starch are given in Tables IV to XII. The measurements were made with the microscope as previously described.

The concentration [41] of the reagents used was as follows:

K_2HPO_4	.100	grams in 100cc.
NH_4Cl	.188	" " "
$CaCl_2$	.100	" " "
$CaCO_3$	.040	" " "
Sugar	10.000	" " "

The numbers represent the grams of the constituent per 100cc.

This is the concentration of the salt in which a protein is the least swollen.

The strength of $\frac{N}{50}$ or $\frac{N}{100}$ acid and alkali was used because it gave the maximum viscosity effect. Gluten has its greatest imbibition of water in $\frac{N}{50}$ solutions as given by Sharp and Gortner [43] in their Physico-Chemical Studies of Strong and Weak Flours.

In the following tables, different solutions were used with wheat starch at a temperature of 40°, 60°, and $80^{\circ}C$. The temperature of $100^{\circ}C$ is not given for the reason that the starch grains had gelatinized beyond the point where measurement was possible.

In the tables "large" stands for the large starch grains, "small" for the small starch grains. The figures are in microns. The gelatinization is given in per cent. The degree of gelatinization is measured by the microscope. As soon as the temperatures given were reached, the solutions were cooled to room temperature. The temperatures given are by the centrigrade scale.

Table V, developes the depressing effect of the salts upon the swelling of the starch grains from that which occurs in water.

Table VI, shows the inhibitory action of salts in the presence of an acid.

Table VII, develops the inhibitory effect of various salts as contrasted with the accelerating effect of an alkali.

Table VIII, shows the inhibitory action of various concentrations of $Ca\ Cl_2$ upon wheat starch.

Table IX, develops the inhibitory action upon wheat starch of a nonelectrolyte.

Table X, shows the different amounts of swelling of wheat starch by various acids under the same conditions. The gelatinization is also represented.

Table XI, develops the swelling and gelatinization of wheat starch under the influence of different alkalies. The alkalies are metals with increasing valences.

Table XII, represents the swelling and gelatinization of starch separated from wheat flour. Various reagents were used at 70°C. In each case they were heated for 15 minutes. The inhibitory action of the salt upon acid and alkali is apparent.

Tables V to XII show the inhibitory action of salts upon wheat starch in acid and alkaline solutions. It develops that the degree of acidity, presence of salts, etc., have their influence upon the starch. Wheat flour contains a large percentage of starch. Influences that affect the starch must, therefore, be considered in bread making. The degree of acidity, salts present, and the temperature used in making the loaf, leave their influence upon the starch. This influence can now be the better understood.

The above conclusions as to the inhibitory influences of salts on wheat starch under the varying conditions, agree with those of Chick and Martin [24] in their study of heat coagulation of proteins.

Tables V to XII follow:

Table V.

ACTION OF SALTS IN H_2O ON WHEAT STARCH.

40° Temperature

Starch Grains Average in Microns	Reagents						
	$Ca\ cl_2$	$Ca\ CO_3$	$K_2\ HPO_4$	$NH_4\ cl$	Sugar	All	H_2O
Large	20.0	22.2	21.5	21.2	18.2	21.0	21.1
Small	5.5	5.4	4.6	4.8	5.0	5.1	5.2
Gelatinization	None	---	---	---	---	---	---
60° Temperature							
Large	24.4	22.5	25.2	23.4	26.1	24.3	26.8
Small	6.2	5.5	5.9	5.8	6.1	6.1	6.3
Gelatinization	35%	25%	30%	25%	30%	20%	40%
80° Temperature							
Large	34.1	31.6	32.7	27.7	34.8	34.0	34.4
Small	8.4	8.1	8.2	8.4	8.4	7.9	8.5
Gelatinization	99%	90%	95%	90%	95%	90%	99%

100° Temperature

Gelatinized beyond measurement.

Table VI.

ACTION OF $\frac{N}{50}$ Hcl and $\frac{N}{50}$ Hcl and SALTS ON WHEAT STARCH.

40^{o} Temperature

Starch Grains	Reagents				
	H_2O	Hcl	Hcl + $Cacl_2$	Hcl + NH_4 cl	Hcl + Sugar
Large	21.1	20.9	20.8	21.8	20.9
Small	5.2	5.5	4.9	4.5	5.2
Gelatin-ization	None	---	---	---	---
60^{o} Temperature					
Large	26.8	33.1	30.0	27.9	22
Small	6.3	7.8	7.7	6.9	6.3
Gelatin-ization	40%	40%	30%	25%	20%
80^{o} Temperature					
Large	34.4	41.2	33.6	30.3	27.5
Small	8.5	9.7	9.6	8.5	9.8
Gelatin-ization	99%	99%	98%	90%	95%

Table VII.

ACTION OF $\frac{N}{50}$ Na OH and $\frac{N}{50}$ Na OH + SALTS ON WHEAT STARCH.

40° Temperature

Starch Grains	Reagents				
	H_2O	NaOH	NaOH + $CaCl_2$	NaOH + NH_4Cl	Na OH + Sugar
Large	21.1	24.0	24.0	21.0	22.4
Small	5.2	6.1	6.1	6.0	6.0
Gelatin-ization	None	---	---	---	---
60° Temperature					
Large	26.8	29.9	29.6	29.7	22.0
Small	6.3	8.2	8.3	8.1	6.9
Gelatin-ization	40%	25%	40%	40%	1%
80° Temperature					
Large	34.4	41.4	40.1	34.7	40.8
Small	8.5	11.6	11.2	9.8	11.3
Gelatin-ization	99%	99%	99%	99%	90%

Table VIII.

DIFFERENT CONCENTRATION EFFECT OF $CaCl_2$ ON

WHEAT STARCH.

40° Temperature

Starch Grains	Reagents			
	H_2O	.1 gm.	1 gm.	10 gm.
Large	21.1	20.0	19.2	20.8
Small	5.2	5.5	5.3	5.9
Gelatinization	None	---	---	---
60° Temperature				
Large	26.8	24.4	24.2	21.0
Small	6.3	6.2	6.4	6.0
Gelatinization	40%	35%	25%	10%
80° Temperature				
Large	34.4	34.1	31.6	33.6
Small	8.5	8.4	8.2	8.4
Gelatinization	99%	99%	80%	60%

Table IX.

DIFFERENT CONCENTRATION EFFECT OF A NONELECTROLYTE SUGAR

ON

WHEAT STARCH

40° Temperature

Starch Grains	Reagents		
	H_2O	1 gm.	10 gm.
Large	21.1	20.4	18.2
Small	5.2	5.5	5.0
Gelatinization	None	----	---
60° Temperature			
Large	26.8	25.6	26.1
Small	6.3	6.2	6.1
Gelatinization	40%	30%	30%
80° Temperature			
Large	34.4	33.5	34.8
Small	8.5	8.4	8.4
Gelatinization	99%	95%	95%

Table X.

ACTION OF DIFFERENT $\frac{N}{50}$ ACIDS AT 60° ON
WHEAT STARCH.

Starch Grains	Reagents					
	H_2O	Hcl	H_2SO_4	H_3PO_4	CH_3COOH	COOH 1 COOH
Large	26.8	33.1	35.4	37.1	30.5	30.1
Small	6.3	7.8	7.1	9.3	8.0	7.4
Gelatin-ization	40%	40%	50%	60%	40 %	40%

Table XI.

EFFECT OF DIFFERENT $\frac{N}{50}$ ALKALIES AT 60° ON
WHEAT STARCH.

Starch Grains	Reagents			
	H_2O	Na OH	$Ca(OH)_2$	Tri
Large	26.8	29.9	24.0	Valent
Small	6.3	8.2	5.6	None
Gelatinization	40%	40%	10%	Soluble

Table XII.

MICROSCOPIC STUDY OF STARCH FROM FLOUR HEATED TO

$70^{o}C$ for 15 MINUTES.

Flour 112

Reagents	Large Grains	Small Grains	Gelatinization
NaOH	40.7	8.9	99%
NaOH + $CaCl_2$	35.6	8.3	98%
HCl	39.1	8.4	99%
HCl + $CaCl_2$	36.7	8.2	98%
$CaCl_2$	32.6	7.1	90%
H_2O	34.2	7.8	95%
Flour 113			
NaOH	41.4	8.7	99%
NaOH + $CaCl_2$	35.5	8.4	98%
HCl	40.1	8.6	99%
HCl + $CaCl_2$	38.2	8.1	98%
$CaCl_2$	33.6	7.3	90%
H_2O	35.4	8.0	95%

Closely related to swelling of the starch and gelatinization, and dependent upon them, is viscosity. The viscosity of the starch would certainly affect the viscosity of the gluten and the viscosity of the dough. In the first of the following experiments on the viscosity of wheat starch, six grams of starch were added to 150c.c. H_2O, thus forming a four per cent starch solution. The time of the tests was taken with a stop watch marked to tenths of a second. An average of five to eight runs was taken. By this method it was possible to check the time of each run to a fifth of a second. The experiments were made at the constant temperature as cited. In this study, the effect of acids and alkali upon starch was determined. The alkali produces colloidal swelling of starch grains greater than that which acids produce as the table following demonstrates. In all the experiments on viscosity, a Scotts Viscosimeter was used. All of the results on viscosity represent an average of six to ten runs.

STUDY OF VISCOSITY OF WHEAT STARCH.

Viscosity [68] of water at room temperature of 20°C was 10.6 seconds. A four per cent solution of wheat starch was used.

Table XIII.

THE VISCOSITY OF A FOUR PER CENT STARCH SOLUTION IN WATER.

Time	50°	60°	70°	80°
10 seconds	10.6	10.6	11.8	12.4
20 "	10.6	10.7	12.2	12.5
30 "	10.65	10.7	12.4	12.9
40 "	10.7	10.8	12.6	13.0
50 "	10.75	10.8	12.8	13.1
60 "	10.8	11.0	12.8	13.1

Table XIV [68] gives the viscosity of starch when treated with Hcl. A four per cent starch solution was used as in the above experiment. The starch solutions were heated and then cooled to 25°C before the viscosity was measured.

Table XIV.

THE VISCOSITY OF A FOUR PER CENT STARCH SOLUTION IN ACID.

Hcl Strength	60°	70°	80°
N	11	11.5	11.2
N/10	11	11.8	12.1
N/100	11.8	12.7	13.2
N/500	11.5	12.1	12.3
N/1000	12.6	12.1	12.6

In the determination of viscosity[6] of the four per cent starch solutions with NaOH, the following data were obtained.

Table XV.

THE VISCOSITY OF A FOUR PER CENT STARCH SOLUTION IN NaOH.

Strength NaOH	60°	70°	80°
N/10	16.3	16.9	13.3
N/50	12.5	13.1	13.0
N/100	11.7	13.1	13.4
N/500	11.9	12.6	13.0

Demoussy [6] states that flour generally acts in an acidic fashion. This acidity affects the gelatinization of the starch, which in turn affects the colloidal chemistry around which bread making is built. The tables show that the viscosity with acid increases as the acid decreases to the strength of one-hundredth of its normal acidity. The last table shows that an alkali decreases the viscosity of a starch solution. However, it becomes evident that a larger amount of alkali increases the viscosity. This seems to confirm the conclusion obtained by MacNider [15]. The tables show that acids and alkali have an action upon starch and they show the effect which may be looked for in bread making. In the bread, the solutions with fermentation are not neutral; generally they are acid, and this has an effect upon the viscosity, or the colloidal properties of the mixture.

It would be expected that the swelling of the starch grains or the increase in size and the accompanying gelatinization of the starch would increase the viscosity. The tables show that this does take place. We also would expect that mixtures not neutral would affect the rate or amount of gelatinization and viscosity. The tables support this conclusion.

The viscosity of the wheat starch was taken with various reagents in order that the change in the starch of a baking loaf might be the better understood. The effect of different salts, acids, and alkalies was studied. The temperature influence was considered. The concentration of the reagents was the same as that used in Tables V-XII. The time to fill a 50c.c. container from 100c. c. in the viscosimeter was taken. In the determinations the viscosity was measured after the solutions were cooled to 20°C. The readings are given in seconds. Four per cent wheat starch solutions were used.

Table XVI gives the viscosity of wheat starch in water and in various salt solutions.

Table XVII develops the viscosity of wheat starch in hydrochloric acid, water and various salts in the same strength of acid. The temperatures of 40°, 60°, 80° and 100°C are used. The inhibitory action of salts is shown in the viscosity measurements.

Table XVIII shows the inhibitory action of salts upon wheat starch in alkaline solutions.

Table XIX develops the influence of different concentrations of calcium chloride upon wheat starch.

Table XX shows the effect of nonelectrolyte, sugar, upon the viscosity of wheat starch. At the higher temperatures and higher concentrations of the sugar, a higher viscosity is given. This is due to the syrup which sugar forms under these conditions.

Table XXI gives the relative influence of various acids upon the viscosity of wheat starch. The temperature of 60°C was used. The strength of the acids was fiftieth normal.

Table XXII develops the effect of various alkalies upon the viscosity of wheat starch. The temperature of 60°C and strength fiftieth normal alkali were used.

Table XXIII gives the influence of various reagents at different temperatures upon the viscosity of starch separated from wheat flour. The wheat flour in Table XXIII was number 112.

Table XXIV gives the same results as Table XXIII upon starch from wheat flour number 113. Flour 113 is a weaker flour than 112. The starch grains in a weak flour are larger than in a strong. The larger starch grains break down first and a slightly higher viscosity should develop. The table shows that this happens.

Tables XVI to XXIV develop the inhibitory effect of salts in the presence of water, acid and alkali. They develop the effect of various acids and alkalies. They show also that viscosity of wheat starch increases with swelling and gelatinization.

The viscosity is given in seconds.

Table XVI.

VISCOSITY OF WHEAT STARCH IN WATER WITH VARIOUS SALTS.

	Reagents						
Temperature: Time in seconds.	$CaCl_2$	$CaCO_3$	K_2HPO_4	NH_4Cl	Sugar	All	H_2O
40°C	14.6	14.7	14.3	14.5	14.3	15.5	14.6
60°	15.4	15.5	15.3	15.4	15.7	15.9	15.5
80°	15.9	16.0	15.9	16.0	17.0	16.9	16.1
100°	16.7	16.9	16.4	16.5	17.3	17.3	16.9

Table XVII.

VISCOSITY OF WHEAT STARCH IN $\frac{N}{50}$ HCl and $\frac{N}{50}$ HCl + VARIOUS SALTS.

	Reagents				
Temperature	H_2O	HCl	HCl + $CaCl_2$	HCl + NH_4Cl	HCl + Sugar
40°	14.6	15.1	15.0	14.2	14.6
60°	15.5	15.6	14.2	14.3	14.2
80°	16.1	16.3	15.5	15.7	15.3
100°	16.9	17.0	15.6	15.8	16.0

Table XVIII.

VISCOSITY OF $\frac{N}{50}$ NaOH and $\frac{N}{50}$ NaOH + SALTS ON WHEAT STARCH.

Temperature	Reagents				
	H_2O	NaOH	NaOH + $CaCl_2$	NaOH + NH_4Cl	NaOH + Sugar
40°C	14.6	14.3	13.7	14.0	14.1
60°	15.5	15.3	14.5	14.7	14.4
80°	16.1	17.1	16.0	15.2	17.5
100°	16.9	17.4	16.0	16.3	17.6

Table XIX.

CONCENTRATION EFFECT OF $CaCl_2$ ON THE VISCOSITY OF WHEAT STARCH.

Temperature	Check H_2O	.1 gm.	1 gm.	10 gm.
40°	14.6	14.6	14.5	14.3
60°	15.5	15.4	15.0	14.4
80°	16.1	15.9	15.5	16.0
100°	16.9	16.7	16.7	17.0

Table XX.

CONCENTRATION EFFECT OF NONELECTROLYTE SUGAR UPON THE VISCOSITY OF WHEAT STARCH.

Temperature	Check H_2O	1 gm.	10 gm.
40°	14.6	14.6	14.3
60°	15.5	15.3	15.7
80°	16.1	16.0	17.0
100°	16.9	16.7	17.3

Table XXI.

EFFECT OF DIFFERENT ACIDS UPON THE VISCOSITY OF WHEAT STARCH AT 60° STRENGTH $\frac{N}{50}$.

H_2O	Hcl	H_2SO_4	H_3PO_4	CH_3COOH	COOH 1 COOH
15.5	15.6	15.7	15.7	15.5	15.4

Table XXII.

EFFECT OF DIFFERENT ALKALIES UPON THE VISCOSITY OF WHEAT STARCH AT 60° STRENGTH $\frac{N}{50}$.

H_2O	NaOH	$Ca(OH)_2$	Tri	Non
15.5	15.3	14.5	Vol.	Sol.

Table XXIII.

VISCOSITY OF WHEAT STARCH FROM FLOUR 112 WITH VARIOUS REAGENTS.

112	20°C	40°	60°	70°	80°	100°
H_2O	14.7	14.8	15.3	15.7	16.0	18.0
NaOH	14.5	14.8	15.5		18.0	19.0
Hcl	14.5	14.7	14.8		16.2	18.0
NaOH + $Cacl_2$	14.5	14.6	14.7		17.6	18.0
Hcl + $Cacl_2$	14.4	14.7	14.8		16.0	17.0
$Cacl_2$	14.6	14.6	15.2		15.7	16.8

Table XXIV.

VISCOSITY OF WHEAT STARCH FROM FLOUR 113.

113	20°	40°	60°	70°	80°	100°
H_2O	14.7	14.8	15.5	16.0	17.0	19.0
NaOH		15.2	15.3	16.4	19.0	20.0
Hcl	14.5	14.7	14.9		16.3	19.0
NaOH + $CaCl_2$	14.5	14.9	15.6		18.0	19.0
Hcl + $CaCl_2$	14.4	14.8	15.5		17.0	17.8
$CaCl_2$		14.6	15.2		15.8	17.0

The inhibition of the salts upon the wheat starch occurs both in the swelling of the grains and in the viscosity. The swelling, gelatinization, and viscosity agreeing gives us more information of what is happening to the starch. The changes in the baking loaf can then be the better understood. The microscopic study of swelling and gelatinization and the study of viscosity lead naturally to consideration of the change in volume during those processes. The measurement of imbibition gives this change in volume of the system. It is desirable to know the nature of the swelling. Therefore, the imbibition of the starch was measured by the increase or decrease in weight of a pycnometer. The starch was subjected to various reagents and temperatures.

The pycnometer had various quantities of flour or starch introduced and weighed. The bottle was filled with the reagent and weighed. It was then heated to different temperatures and cooled to 20°C, filled to the mark, and weighed. The amount of increase or decrease was calculated on a one gram basis. The weight changes which occurred from 20° to 40°C, from 40° to 60°, etc., are given. At the end of each table a summary of that table is given of the total change in weight that occurs from 20° to 80°C. Temperature above 80°C was not employed because of the great decomposition of the starch into the soluble form.

Table XXV considers the imbibition of wheat flour entire in water. Seventeen flours were used.

Table XXVI gives the imbibition of starch separated from wheat flour. This starch was purified with alcohol and ether. The shrinkage is given on a gram basis of flour.

Table XXVII develops the shrinkage of the system of wheat starch and water. The starch was separated from the flour as in Table XXVI but not purified with alcohol and ether. Practically the same results were obtained.

Table XXVIII is given to represent the accuracy of the imbibition measurements. Flour Number 109 was used. Three different runs were made. They check within the limits of experimental error.

Table XXIX shows the imbibition of wheat starch with various reagents. The results show the inhibition effect of salts upon acid and alkalies. They agree with the results obtained from the microscope and from Viscosity measurements. The strength of the acid and alkali is fiftieth normal.

Table XXX gives the imbibition of different starches. Starches with different sizes of grain were selected. The starch grains of potatoes were the largest, of wheat the next, of maize still smaller, and of rice the smallest. In previous data, the smaller granules of starch proved to be the more resistant. This property is shown to hold here.

Tables XXXI and XXXII develop the imbibition of wheat flour entire. Flours used were No. 112 and No. 113. A heating period of fifteen minutes was used. The inhibitory action of salts in presence of acids and alkalies upon the starch is again noticed.

Tables XXXIII and XXXIV give the effect of imbibition of various reagents upon starch separated from wheat flour. The inhibitory action of salts is again shown. Starch from flour 112 being smaller imbibes less water. This again shows the greater resistance of the smaller grains.

Table XXXV gives the imbibition of different flours with various reagents. Table XXXVI gives the imbibition of starch from these flours. In tables XXXV and XXXVI, a constant temperature was used. The total imbibition up to one hour is given in each case. A DeKotinsky equal temperature bath was used. A temperature control to a tenth of a degree was possible. The temperature of 30°C was used.

Table XXXVII gives the rate of imbibition of water by flours No. 112 and No. 113. The data will give a curve very similar to an adsorption curve. These are typical of the increase in weight per gram of flour for this series. The rate of hydrolysis may be an important factor in the explanation of the action in the different tables on imbibition.

Table XXV.

IMBIBITION OF WHEAT FLOUR ENTIRE IN H_2O PER GRAM

Flour No.	— Temperatures — 20°- 40°C	40° - 60°	60° - 80°	80° - 100°
102	.0140	.0070	.0033	- .0150
103	.0050	.0122	.0054	- .0200
112	.0228	.0220	- .0050	- .0100
104	.0171	.0048	.0043	- .0052
105	.0126	.0005	.0058	- .0020
106	.0176	.0076	.0022	- .0054
107	.0280	.0064	- .0168	-.0110
116	.0240	.0085	- .0083	- .0022
115	.0222	.0044	.0022	- .0150
100	.0122	.0144	- .0068	- .0026
111	.0267	.0177	- .0114	- .0165
109	.0206	.0103	- .0119	- .0058
101	.0121	.0148	- .0094	- .0031
110	.0195	.0110	- .0040	- .0080
113	.0120	.0090	- .0030	- .0050
108	.0118	.0058	- .0010	- .0058
114	.0145	.0100	- .0007	- .0110

THE IMBIBITION SUMMARY FROM 20°-80°C FROM PRECEDING DATA

Flour No.	113	107	108	105	102	116	115	100
Summary	.0180	.0176	.0166	.0189	.0243	.0242	.0186	.0168

SUMMARY OF TABLE XXV (Continued).

Flour No.	103	104	112	106	111	109	101	110
Summary	.0226	.0262	.0398	.0274	.0330	.0185	.0175	.0265

Table XXVI.

IMBIBITION PER GRAM OF STARCH SEPARATED FROM FLOUR WITH H_2O AND PURIFIED WITH ALCOHOL AND ETHER.

Flour No.	— Temperatures —			
	20° - 40°	40°-60°	60° - 80°	80° - 100°
102	.0030	.0050	.0056	- .0090
103	.0060	.0090	- .0030	- .0064
112	.0050	.0035	- .0065	- .0075
104	.0050	.0032	.0011	- .0048
105	.0035	.0022	.0078	- .0013
106	.0025	.0025	.0050	- .0062
107	.0030	.0020	.0092	- .0028
108	.0040	.0045	.0050	- .0030
116	.0018	.0036	.0062	- .0091

THE IMBIBITION SUMMARY FROM 20°-80° FROM PRECEDING DATA

Flour No.	102	105	107	116	103	112	104	106	108
Summary	.0136	.0135	.0142	.0116	.0120	.0020	.0093	.0100	.0135

Table XXVII.

IMBIBITION PER GRAM OF STARCH SEPARATED FROM FLOUR

WITH H_2O.

Flour No.	— Temperatures — 20°-40°	40°-60°	60°-80°	80°-100°
105	.0056	.0069	.0006	- .0060
106	.0025	.0004	.0060	- .0029
107	.0050	.0020	.0060	- .0045
108	.0081	.0018	.0049	- .0044
112	.0136	.0015	- .0112	- .0050
103	.0086	.0078	- .0038	- .0049
104	.0150	.0015	- .0068	- .0043
116	.0120	.0010	- .0020	- .0080
102	.0050	.0020	.0048	- .0060
111	.0120	.0022	- .0100	- .0020
109	.0137	.0020	- .0020	- .0060
100	.0107	.0044	- .0018	- .0100
113	.0109	.0029	.0005	- .0030
115	.0110	.0020	- .0049	- .0050
110	.0120	.0022	- .0035	- .0040
114	.0100	.0030	- .0020	- .0035
101	.0091	.0045	.0005	- .0060

THE IMBIBITION SUMMARY FROM 20°-80° FROM THE PRECEDING DATA

Flour No.	105	107	116	102	109	100
Summary	.0131	.0130	.0110	.0118	.0137	.0133

SUMMARY OF TABLE XXVII (Continued).

Flour No.	113	106	112	103	104	108	111
Summary	.0145	.0089	.0039	.0126	.0097	.0148	.0044

Table XXVIII

IMBIBITION OF WHEAT FLOUR 109 IN WATER.
Checks per gm.

20°-40°	40°-60°	60°-80°	80°-100°
First Run			
.0180	.0121	- .0127	- .0042
.0198	.0129	- .0124	- .0049
.0200	.0111	- .0111	- .0033
.0254	.0075	- .0121	- .0020
Second Run			
.0168	.0090	- .0104	- .0041
.0184	.0068	- .0084	- .0122
.0241	.0088	- .0118	- .0100
.0200	.0138	- .0168	- .0062
Third Run			
.0161	.0140	- .0092	- .0068
.0140	.0080	- .0062	- .0022
.0119	.0070	- .0026	- .0074
.0167	.0158	- .0117	- .0090

Last with 100c.c. Absorption bottles.

IMBIBITION SUMMARY FROM 20° - 80°.

First Run	.0196
Second Run	.0176
Third Run	.0184
3	.0556
	.0185 Final Average

Table XXIX.

WHEAT STARCH IMBIBITION IN TERMS 1 GRAM

Reagents	20°-40°	40°-60°	60°-80°	80°-100°
H_2O	.0053	.0112	.0053	- .0078
Hcl	.0100	.0520	.0060	- .0022
Hcl + $CaCl_2$	.0020	.0125	.0000	- .0250
NaOH	.0233	.0121	- .0098	- .0041
NaOH + $Cacl_2$	.0080	.0050	.0090	- .0105
$Cacl_2$	.0010	.0196	.0003	- .0238

Table XXX.

IMBIBITION OF DIFFERENT STARCHES IN H_2O

	20°-40°	40°-60°	60°-80°	80°-100°
Potato	.0369	.0060	- .0087	- .0038
Wheat	.0053	.0112	.0053	- .0078
Maize	.0031	.0105	.0050	- .0198
Rice	.0011	.0124	.0117	+ .0110 On boiling - .0220

Table XXXI.

IMBIBITION OF WHEAT FLOUR ENTIRE SAMPLE 112.

Flour 112.

Reagents	— Temperatures —				Summary
	20°-40°	40°-60°	60°-80°	80°- 100°	20°-80°
NaOH	.0200	.0230	-.0030	-.0120	.0400
Hcl	.0100	.0180	.0065	-.0030	.0345
$Cacl_2$	.0080	.0075	.0035	-.0040	.0190
NaOH + $Cacl_2$	.0100	.0075	.0050	-.0260	.0225
Hcl + $Cacl_2$	.0100	.0130	.0060	-.0050	.0290

Table XXXII.

IMBIBITION OF WHEAT FLOUR ENTIRE SAMPLE 113.

Flour 113.

Reagents	— Temperatures —				Summary
	20°-40°	40°-60°	60°-80°	80°-100°	20°-80°
NaOH	.0100	.0210	-.0030	-.0100	.0280
Hcl	.0120	.0260	-.0105	-.0180	.0275
NaOH + $Cacl_2$	.0100	.0205	-.0090	-.0110	.0215
Hcl + $Cacl_2$	.0080	.0185	-.0045	-.0120	.0220
$Cacl_2$	.0080	.0065	.0030	-.0040	.0175

Table XXXIII.

IMBIBITION OF STARCH FROM WHEAT FLOUR.

Flour 112

Reagents	— Temperatures — 20°-40°C	40°-60°	60°-80°C	80°-100°	Summary 20°-80°
NaOH	.0075	.0120	-.0030	-.0130	.0165
$CaCl_2$	.0040	.0070	-.0020	-.0090	.0090
Hcl	.0080	.0115	-.0090	-.0110	.0105
NaOH + $CaCl_2$	.0070	.0100	-.0010	-.0110	.0160
Hcl + $CaCl_2$	.0060	.0110	-.0060	-.0080	.0110

Table XXXIV.

IMBIBITION OF STARCH FROM WHEAT FLOUR.

Flour 113

Reagents	— Temperatures — 20°-40°	40°-60°	60°-80°	80°-100°	Summary 20°-80°
NaOH	.0100	.0160	.0040	-.0110	.0300
Hcl	.0095	.0135	.0030	-.0125	.0260
$CaCl_2$	.0045	.0075	.0035	-.0080	.0155
NaOH + $CaCl_2$	.0080	.0153	-.0020	-.0160	.0213
Hcl + $CaCl_2$	.0090	.0120	.0030	-.0115	.0240

Table XXXV.

IMBIBITIONS OF DIFFERENT FLOURS WITH VARIOUS REAGENTS

AT 30°C for 1 Hr.

Reagents	— Flours —			
	112	111	109	113
H_2O	.0084	.0090	.0105	.0110
Hcl	.0104	.0112	.0114	.0121
Hcl + $Cacl_2$	.0090	.0092	.0092	.0110
NaOH	.0102	.0108	.0100	.0122
NaOH + $Cacl_2$	.0096	.0102	.0096	.0113

Table XXXVI.

IMBIBITION OF STARCH FROM DIFFERENT FLOURS WITH VARIOUS

REAGENTS AT 30°C for 1 Hr.

Reagents	— Flour Starches —			
	112	111	109	113
H_2O	.0066	.0116	.0102	.0150
Hcl	.0098	.0100	.0110	.0134
Hcl + $Cacl_2$	.0086	.0090	.0100	.0120
NaOH	.0082	.0092	.0084	.0128
NaOH + $Cacl_2$	.0052	.0080	.0092	.0124

Table XXXVII.

RATE OF IMBIBITION OF WATER FOR FLOURS

NOS. 112 and 113.

Time Increments in Minutes	Flour 112 Increase per gram of flour	Flour 113 Increase per gram of flour
10	.0044 grams	.0060
10	.0014	.0010
20	.0009	.0016
20	.0006	.0008
20	.0001	.0008
20	.0004	.0002

The data on imbibition show the same general inhibition when salts are added to acid or alkali solutions. With a play of temperature the imbibition of a good flour is larger than that of a poor flour. The colloidal conditions are better. In case of starch from flour as the temperature increases, the poor flour having the largest starch grains imbibes the most water. The large starch grains are less resistant than the small starch grains. At constant temperature, the poorer the flour, the greater the shrinkage because the large starch grains being less resistant imbibe more water.

Experimental data also supporting this last statement are given in Table XXXVIII. The results here tabulated, were obtained from experiments in which three different starches were subjected to the temperatures of 70° and 80°C. Four gram samples in 100c.c. water were used. The insoluble starch was filtered from the soluble starch. The insoluble starch was made up to 100 cc after each filtering. The soluble starch was then dried and weighed.

Table XXXVIII.

SOLUBLE STARCH FORMED BY HEAT AND OBTAINED BY FILTERING.

	— Starches Used —		
Temperature	Potato	Rice	Wheat
70°C	.5020 gram	.0320 gram	.0360 gram
80°C	Too thick to filter	.0680	.1520
Size of the Starches in Microns	60 - 70	5 - 8	20 - 30

The data show that rice starch grains are smallest and most resistant; those of the potato the largest and least resistant. The wheat starch falls in between the rice and potato starch.

Further research in this laboratory on imbibition of gluten as well as on starch, is contemplated for the year 1923-24.

To correlate the microscopic data, and the data relative to viscosity and imbibition with baking tests, the experiments recorded in Tables XXXIX and XLI were conducted:

The first baking tests were patterned after Bailey's[9] experiment. The ingredients used for the first series of baking, were:

Yeast	5.5	grams
Salt	6.75	"
Sugar	11.25	"
Flour	450	"

The amount of water was determined by running an absorption test on each of the flours. The dough was worked together by an electric mixer. Each loaf was in this machine three minutes. The dough was then placed in earthen jars and put into a fermentation cabinet at 35°. This cabinet was kept saturated with water vapor. The dough was allowed to rise about two hours and then knocked down. After another rising period of one hour, the dough was placed into baking pans. Five hundred and fifty grams of dough were used for each pan. The dough in the pans was allowed to stand for two hours until it reached a certain height. It was then baked for thirty minutes in an electric oven. The temperature of the oven at starting, was 190°C, and at finishing, 200°C. The oven was saturated with water vapor in order that a heavy crust might not form on the bread. After baking, the bread was cooled over night. The volume, weight and texture of the loaf was then determined. The volume of each loaf was then measured by the displacement method of hemp seed.

In order to minimize errors, which are very hard to avoid in work of this character, one loaf of each batch was prepared as a control and it contained the same ingredients in each experiment. The experiments were repeated two or three times and an average of the results was taken.

Sixteen different flour [68] samples were used. In the table following, each figure of size representing the starch grains is an average of a hundred or more microscopic measurements.

Table XXXIX.

COMPARISON OF LOAF VOLUME TO SIZE OF STARCH GRAINS, ABSORPTION, etc.

me of in c.c.:	Wt. of loaf :	No. of Flour:	Starch grain sizes in microns. Large Grains:	Small Grains:	Ratio Small to Large Grains:	Absorption
240	482	Four	20.7	5.2	4-1	50.2
265	496	Eleven	22.6	5.1	3.5-1	54.4
300	471	Eight	20.3	4.8	5-1	50.0
310	481	Two	21.2	4.6	3.6-1	54.0
360	489	Nine	22.6	4.9	3-1	54.0
390	484	Seven	19.6	4.5	4-1	54.6
400	483	Fourteen	21.0	5.4	3.5-1	56.2
400	487	Five	19.0	4.9	4-1	55.2
415	490	Six	18.4	4.4	4.6-1	58.0
500	473	Ten	20.9	4.9	3.3-1	54.5
500	483	Three	17.6	4.1	5-1	54.2
540	491	One	19.4	4.6	4.8-1	57.2
565	517	Twelve	19.2	4.4	5-1	56.2
600	487	Sixteen	18.3	4.6	5-1	54.5
640	485	Thirteen	18.4	4.9	6.3-1	55.6
710	492	Fifteen	18.8	4.4	5.3-1	54

On examining the above data, several relations are discovered. Generally, the loaf of the larger volume results from the better or stronger flour. Ostwald [76] states that in the stronger flour the colloidal conditions must be better. Small particles favor better colloidal conditions. That is, the ratio of small particles to the number of large particles and the size of the particles would certainly affect colloidal conditions. The smaller the size of the large particles and the larger the ratio of small particles to large ones, the larger would become the loaf. The table develops in general that the samples of flour producing the larger volume loaf have smaller size of starch grains. The larger becomes the ratio of small grains to large ones, the larger the volume of the loaf. An average small size of the starch grains would indicate a strong flour.

It was noticed that the flour [68] varied as to number of the different sizes of the starch grains. This is shown in the following table:

Table XL.

Diameter of starch grains	The flour number. Six	Five	Four	Eight
30 microns or above	9	8	7	9
25 " — 29	9	8	11	9
20 " — 24	20	23	27	28
16 " — 19	28	24	22	24
12 " — 15	16	13	18	18
8 " — 11	10	9	15	13

It is shown that the distribution of the large starch grains follows fairly well the regular distribution curve so often found in nature.

The second series of baking tests was conducted a year after that of Table XXXIX on other flours [68]. The baking was conducted by the experimental baker [51]. The directions were practically the same as those followed a year previous. They were patterned after Bailey's [2] experiment. The ingredients for the second series of flours were:

Flour	800	grams
Sugar	32	"
Salt	12	"
Yeast	20	"

Two loaves of bread were made from this amount, each loaf using 500 grams of dough. The dough was worked together by hand for seven minutes. The fermentation cabinet temperature of 30°C was used. A control was used. The other directions are the same as before.

The results coincide and the same relations hold as pointed out in the preceding work. Table XLI follows:

Table XLI.

Loaf Size	Dough Maximum Swelling	Absorption Water	Moisture	Ash Dry Basis	Nitrogen Dry Basis	Starch Grains Large	Starch Grains Small	% Large Grains	Flour Imbibition in Pycnometer	Starch Imbibition
Standard	920	65%	8.7%	.42	10.4	18.6	4.6	14.1	.0398	.0039
-70	860	65	9.1%	.54	11.1	18.8	4.4	14.9	.0330	.0044
-100	830	61	8.8%	.63	11.5	21.1	5.7	16.8	.0185	.0137
-300	660	56	8.5%	.78	11.2	21.4	5.9	17.3	.0180	.0143

Table XLI shows that as the starch grains increase in size the loaf decreases. The wheat giving the larger loaf has a larger imbibition. The starch from the same wheat flour shows a lower imbibition. The better flour starch grains are on the average smaller. The smaller starch grains are more resistant. Thus a better colloidal condition is obtained in the better grades of flour.

Poor flour often comes from soft wheat. Soft wheat is generally raised in countries where moisture is plentiful. Large amounts of moisture tend to increase the size of the starch grains. So in the poor flour the starch grains are larger and there are few small starch grains. On the other hand, a dry climate generally produces a harder wheat. The grains of starch do not have sufficient moisture to grow to large sizes. There are, in such cases, a large number of small grains of starch. Substances that are finely divided produce better colloidal conditions. Bread making is dependent entirely upon colloidal phenomenon. The better the colloidal conditions, the better and larger is the size of the loaf.

The preceding data developed the amount of swelling, gelatinization, viscosity, and imbibition of starch grains in relation to temperature, time, and various reagents.

The same effect was developed upon flour and correlated to the action upon wheat starch alone. The viscosity of the starch and flour solutions was studied and the effect of acids, alkalies, and salts was discovered. The imbibition of flour and starch was studied under the influence of acids, alkalies, and salts. These results explain the reactions that occur in the loaf. The viscosity, swelling, gelatinization, absorption, and adsorption or imbibition of the wheat starch materially affect the size of the loaf. The baking tests were made to apply the knowledge of these colloidal properties, to the finished loaf. These colloidal properties can be used in determining the quality of a flour.

SUMMARY AND CONCLUSION.

1. The original work upon which this paper is based, covers a series of three main experiments.

a. A microscopic study of wheat starch and wheat flour was made determining the effect of acids, bases and salts under varying conditions of temperature and time.

b. A viscosity study of wheat starch and wheat flour was made with the same reagents and under the same conditions as the microscopic study.

c. The effect of the same reagents and conditions upon the imbibition of wheat starch and wheat flour was also studied.

2. It is concluded there is a relationship between the above colloidal properties and the baking size of the loaf for the following reasons:

a. The size and number of the starch grains would affect the colloidal properties and thereby the size of the loaf.

b. Small starch grains tend to indicate a strong flour.

c. The viscosity of the starch grains and flour dough would affect the size of the loaf. The reagents that influence this viscosity would thereby affect the size of the loaf.

d. The imbibition that the starch undergoes, influences the amount of water necessary to mix the dough and the moisture condition of the loaf. The reagents that influence the imbibition of the starch, therefore, directly affect the loaf.

e. Therefore there is a relationship between the above colloidal properties and the volume of the loaf.

BIBLIOGRAPHY.

1. Allen's

Commercial Organic Analysis Vol. 1.

2. Alway, F. J. and Hartzell, S.

On Strength of Wheat Flour -- 23d Annual Report Neb. Agr. Exp. Sta.

3. Armstrong, E. F.

The Chemical Properties of Wheaten Flour.--Supp. J. Board Agr. XVII 45.

4. Arpin

Industrial Classification of Starches. Ann. Chim. Anal. Chim. Appl. 3, 74.

5. Atwater, H. W.

Bread and Bread Making. U. S. Dept. Agr. Farmer's Bul. 389, 47.

6. Bacon, R. F.

The Use of Mineral Salts in Bread Making. National Bakers XXI No. 243, 39.

7. Bailey, C. H.

A Method for the Determination of the Strength and Baking Quality of Wheat Flour. J. Ind. and Eng. Chem. 8, 53.

8. Bailey, C. H.

Milling and Baking and Chemical Tests. Minn. Univ. Bulletin 131, 1913.

9. Bailey, C. H.

A Simple Hydrogen Electrode. J. Am. Chem. Soc. 42, 45.

10. Bailey, C. H. and Collatz, F. A.

Studies of Wheat Flour Grades I Electrical Conductivity of Water Extracts.
Science 51, 374 (1920).

11. Bailey, C. H. and Peterson, A. C.

Wheat Flour Grades.
J. Ind. Eng. Chem. 13, 916.

12. Bailey, C. H. and Weigley, M.

Loss of CO_2 From Dough as an Index to Flour Strength.
J. Ind. Eng. Chem. 14, 147, 1922.

13. Baker, J. L. and Hulton, H. E. F.

Conditions Affecting the Strength of Wheaten Flour, 1908.
Jour. Soc. Chem. Ind. 27, 368.

14. Baker, J. L. and Hulton, H. E. F.

Action of Malt Enzymes on the Enzymes of Ungerminated Cereals.
Analyst 33, 392.

15. Baker, J. L. and Hulton, H. E. F.

Action of Diastase on Starch Granules.
Jour. Chem. Soc. (London) 105, 1529.

16. Bolland, A.

Fatty Matters and Acidity of Flour.
Comptes. Rend. 137, 724.

17. Blish, M. J.

On the Chemical Constitution of the Proteins of Wheat Flour and its Relations to Baking Strength.
Jour. Ind. Eng. Chem. 7, 138.

18. Barth, G.

Testing the Baking Quality of Flour.
Ztschr. Untersuch. Nahr. U. Genusmth, 5,449.

19. Buchanan, J. H.

Research on Imbibition of Water in Various Reagents With Flour.
I. S. C. 1923.

20. Buchanan, J. H. and Naudain, G. G.

The Influence of the Starch on the Strength of Wheat Flour.
Paper Accepted by Jour. Ind. and Eng. Chem. June 1923.

21. Chamberlain, J. S.

Determination of Gliadin and Glutenin in Flour by the Fleurent-Manget Method.
U. S. Dept. of Agr. Bur. Chem. Bul. 81, 118.

22. Chamberlain, J. S.

Investigations on the Properties of Wheat Proteins.
J. Am. Chem. Soc. 28, 1657.

23. Chapman, O. W.

A Study of the Refractive Index of Water Extracts of Wheat Flour.
1921 Thesis I. S. C.

24. Chick and Martin

Heat Coagulation of Protein.
J. Physiol. 45, 61.

25. Cohn, E. J. and Henderson, L. J.

The Physical Chemistry of Break Making.
Sci. 48, 501.

26. Cohn, E. J. and Cathcart, P. H. and Henderson, L. J.

The Measurement of the Acidity of Bread.
Jour. Biol. Chem. 36, 581.

27. Collatz, F. A.

Flour Strength as Influenced by the Addition of Diastatic Ferments.
Am. Inst. Baking Bul. 9.

28. Courtonne.

The Opposite Effect of Chlorides and Sulphates on Starches.
Compt. Rend. 171, 1168.

29. Demoussy.

Acidic Properties of Starch.
Compt. rend. 1906, 142, 933.

30. Dox and Roark.

Determination of Gelatinization of Starches by Means of an Electrically Heated Chamber on the Microscope Stage.
J. Am. Chem. Soc. 39, 742.

31. Ermen.

The Examination of Commercial Starches.
J. Soc. Chem. Ind. 26, 501.

32. Fernbach, A.

Recent Progress in our Knowledge of Starch.
J. Inst. of Brewing Vol. 15, 330.

33. Fernbach, A. and Wolff, J.

Circumstances which Influence the Physical Condition of Starch.
Compt. Rend. 1905, 140, 1403.

34. Fernbach, A. and Wolff, J.

Mechanism of the Influence of Acids, Bases and Salts in the Liquefaction of Starch Paste.
Compt. Rend. 1906, 143, 380.

35. Fisher, M.

On the Swelling of Fibrin in Poly-basic Acids and their Salts.
Jour. Am. Chem. Soc. 40, 292.

36. Fouard.

Recent Progress in our Knowledge of Starch.
Compt. Rend. 1907.

37. Fouard.

Researches on the Physico-Chemical Constitution of Starch.
J. Inst. of Brewing, Vol. 15, 633.

38. Fouard.

The Colloidal Properties of Starch.
Compt. Rend. 144, 1366.

39. Ford, J. S. and Guthrie, J. M.

The Amylolytic and Proteolytic Ferments of Wheat Flours and their Relations to Baking Value.
Jour. Soc. Chem. Ind. 27, 389.

40. Francis and Smith.

The Determination of the Gelatinization Temperature of the Starches from the Grain Sorghums, by means of a Thermo-slide.
J. Ind. and Eng. Chem. 8, 509.

41. Fulmer, E. I., Nelson, V. E. and Sherwood, F. F.

The Nutritional Requirements of Yeast.
II. The Effect of the Composition of the Medium on the Growth of Yeast.
I. S. C. 1921. Jour. Am. Chem. Soc., Jan. 1921.

42. Gortner, R. A. and Doherty, E. H.

Hydration Capacity of Gluten from Strong and Weak Flours.
Jour. Agr. Res. 13, 389.

43. Gortner, R. A. and Sharp, P. F.

Physico-Chemical Properties of Strong and Weak Flours.
Jour. of Phys. Chem. 26, 1922, 1.

44. Greaves, J. E.

Some Factors Influencing the Quantitative Determination of Gliadin.
Jour. Biol. Chem. 9, 271, 1911.

45. Greenish.

Microscopic Examination.

46. Guess, H. A.

The Gluten Constituents of Wheat and Flour and their Relation to Bread Making Qualities.
J. Am. Chem. Soc. 22, 263.

47. Guthrie, F. B. and Norris, G. W.

Notes on Flour Strength.
Jour. Proc. Royal Soc. N. S. Wales, 43, 171.

48. Hardy, W. B.

An analysis of the Factors Contributing to Strength of Wheat Flour.
Supp. to Board of Agr.-- Winnipeg, Can. 17. 52, 1910.

49. Hartzell, A. F.

On the Strength of Wheat Flour.
23d Annual Report
Neb. Agr. Exp. Sta. P.100.

50. Hawks, J. W.

The Influence of Certain Inorganic Salts in Bread Making.
M. S. Thesis I. S. C., 1917.

51. Hawks, J. W.

Research on Baking Quality of Various Flours.
I. S. C. 1923.

52. Henderson, L. J., Fenn, W. and Cohn, E. J.

Influence of Electrolytes on Viscosity of Dough.
J. Gen. Physiol. 1, 387.

53. Humphries, A. and Simpson, A. G.

Gas Making Capacity as a Factor in the Estimation of Strength in Wheaten Flour.
7th Intern. Cong. Appl. Chem.---Starch Sect. P.27.

54. Jago, Wm. and Wm. C.

Technology of Bread Making.

55. Kohman, H. A.

Effects of Mineral Salts on Fermentation.
Bakers Weekly, October 1915.

56. Kohman, Hoffman, Godfrey, Ashe, and Blake.

On the Use of Certain Yeast Nutriments in Bread Making.
J. Ind. Eng. Chem. 8, 78.

57. Komers, K. and Haunalter, E.

Estimating the Value of Wheat Flours by Means of Baking Tests.
Ztschr. Landw. Versuchw. Oesterr, 5:1225.

58. Kraemer.

The Influence of Heat and Chemicals on the Starch Grain.
Orig. Can. 8th Intern. Congr. Appl. Chem. 17, 31.
Am. J. Pharm. 86, 81.

59. La Wall and Graves.

Gelatinization of Starches.
Trans.
Wagner Free Inst. Sci. Phila. 7 Pt. 2.

60. Lawellin.

The Ash Test for Flour and its Value.
Natl. Miller 27, 35, 1922.

61. Leach.

Food Inspection and Analysis.

62. Lintner, C. J.

Studies on Diastase.
J. Prakt. Chem. 2, 34, 378.

63. Lipenkin.

The Heat Coagulation of Proteins.
Biochem. J. 16, 678, 701.

64. MacNider, G. N.

A Method for Determination of the Value of Commercial Starches for use in Cotton Mills.
J. Ind. and Eng. Chem.
1912, 417----1920, 420.

65. Martin, F. J.

Properties Effecting Strength in Wheaten Flours.
J. Soc. Chem. Ind. 39, 246.

66. Masters, H. and Maughan, M.

An Experimental Study of the Effect of Certain Organic and Inorganic Substances on the Bread Making Properties of Flour and on the Fermentation of Yeast.
Biochem. 586, Vol. 14, 1920.

67. Mentscheller, A.

Colloidal Adsorption.
J. Am. Chem. Soc. 42, 1242.

68. Naudain, G. G.

A Study of the Properties of Wheat Starch With Reference to Flour.
M. S. Thesis, I. S. C. 1922.

69. Newmann.

Influence of the Addition of Foreign Starches Upon the Quality of the Dough.
Z. Geasm. Getreidew 4, 18.

70. Norton, F. A.

Crude Gluten.
J. Am. Chem. Soc. 28, 8.

71. Nyman.

The Gelatinization Temperature of Starch Grains.
Zeitsch. Nahr. Genussm. 24, 673.

72. Olson, G. A.

Is Gluten Necessary for Making of Good Bread?
Operative Miller 16:449.

73. Olson, G. A.

Composition of Dry Gluten and its Relation to Protein Content of Flour.
J. Ind. and Eng. Chem. 4, 206.

74. Olson, G. A.

Wheat and Flour Investigations.
St. Col. of Wash. Bul. 144.

75. Osborn, T. B. and Voorhees, C. G.

The Proteins of Wheat Kernels.
Am. Chem. Jour. 15, 392.

76. Ostwald.

Colloidal Chem. of Bread 1. Colloidal Chemical Problems in the Preparation of Bread.
Leipzig Kolloid Z. 25, 26, 45.

77. Ostwald and Riedel.

The Preparation of Bread from Starch.
Kolloid Z. 12, 4 (1915).

78. Rakovskii.

Adsorption of Substances Dissolved in Water by Starch.
J. Russ. Phys. Chem. Soc. 44, 586.

79. Reichert, E. T.

The Specificity of Proteins and Carbohydrates in Relation to Genera, Species and Varieties.
Am. J. Botany. 3, 91.

80. Reychler, A.

Studies on Starch.
Bulletin Soc. Chim. 29, 309.

81. Robertson, T. B.

The Physical Chemistry of the Proteins.
Longmans, Green and Co. 1920.

82. Rumsey, L. S.

The Diastatic Enzymes of Wheat Flour and their Relation to Flour Strength.
Thesis U. of Minn. 1922.

83. Samec.

The Solution Swelling of Starch in Presence of Crystalloids.
Koll. Chem. Beihefte 1911, 3, 123.

84. Samec.

Variations in the Phosphorous Content of Starch Accompanying its Change of State and its Diastatic Conversion.
J. Inst. Brew. 1914, 20, 716.

85. Saunders.

Researches in Regard to Wheat Flour and Bread.
Can. Expt. Farms. Bul. 97, 57.
J. Ind. Eng. Chem. 14, 793.

86. Sherman, H. C. and Neun, D. E.

The Influence of Certain Animo Acids upon the Enzymic Hydrolysis of Starch.
Jour. Am. Chem. Soc. 43, 2461.

87. Sherman, H. C., Walker, F. and Caldwell, M. L.

Action of Enzymes upon Starches of Different Origin.
J. Am. Chem. Soc. 41, 1123.

88. Shutt, F. T.

A Chemical Study of the Grain and Flour of the Grades of Wheat.
Central Exp. Farm, Ottawa, Canada,
Bulletin 50.

89. Snyder, H.

Wheat Flour and Bread.
U. S. Dept. Agr. Year Book 347.

90. Snyder, H.

The Determination of Gliadin in Wheat Flour by Means of the Polariscope.
Jour. Am. Chem. Soc. 26, 263.

91. Thatcher, R. W.

A Comparison of Various Methods of Estimating the Baking Qualities of Flour.
J. Am. Chem. Soc. 29, 910.

92. Thatcher, R. W. and Kennedy, C.

Adsorption of Flour Enzymes by Gluten Colloids.
Reported at Boston Meeting--Am. Chem. Soc. Div. of Biological Chem. September, 1917.

93. Thatcher, R. W., Olson, G. A., and Hadlock, W.

Wheat and Flour Investigation of Crops 1908.
Wash. Agr. Exp. Sta. Bul. 100.

94. Teller, G. L.

A Report of Progress of Investigations in the Chemistry of Wheat.
Arkansas Agr. Exp. Sta. Bul. 53.

95. Teller, G. L.

The Carbohydrates of Wheat and Wheat Products and Changes in Same During Development of the Grain.
8th Intern. Cong. Appl. Chem. Sect. VI P.273.

96. Upson, F. W. and Calvin, J. W.

The Colloidal Swelling of Wheat Gluten in Relation to Milling and Baking.
Univ. of Nebraska, Bul. No. 8.

97. Upson, F. W. and Calvin, J. W.

On the Colloidal Swelling of Wheat Gluten.
J. Am. Chem. Soc. 37, 1295.

98. Weaver, and Goldtrap.

A General Review of Flour.
The Jour. of Am. Assc. of Anal. Chemist.
July 1922---Vol. VII.

99. Williard, J. T., and Swanson, C.

Baking Qualities as Influenced by Certain Chemical Substances.
Chem. News 1912, 105, 97.

100. Winton.

Microscopy of Vegetable Foods.

101. Wolff and Fernbach.

Adsorption of Starch.
J. Am. Chem. Soc. 1911, 33, 1213.

102. Wood, T. B.

The Chemistry of Strength of Wheat Flour.
Jour. Agr. Sci. 2, 139, 267.

103. Woodman.

Food Analysis.