THE COMBINED EFFECTS OF SALT AND ACID ON WHEAT FLOUR STRENGTH

by

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INTRODUCTION

A number of investigators have studied the separate effects of salts and acids on the physical properties of wheat-flour doughs (1-25). However, few references were found that dealt with the combined effects of acids and salts on dough rheology (11, 20, 26).

The importance of the rheological properties of dough arises from the correlations that have been established or are believed to exist between these properties and the quality of the baked products on one hand and flour or dough composition and structure on the other hand (37).

The objective of the present investigation was to study the combined effects of hydrochloric acid and sodium chloride on the strength and the quality of wheat flour as measured by the physical properties of dough and baking tests.

The results obtained, procedures employed, observations are herein presented and discussed.

LITERATURE REVIEW

Flour Strength

Pyler (1) indicated that flour strength is difficult to define concisely. This is largely because flour quality is reflected by a variety of physical characteristics of the dough, none of which serves as an adequate index by itself or is independent of other variables. Thus, different physical testing methods, different test formulas, and different dough treatments, when applied to the same flour, will yield results which may lead to divergent conclusions as to the flour's quality.

However, various definitions of flour strength have been proposed (2, 3, 4). One of the earliest was that of Kent Jones (2), who stated that strength is the ability of flour to be converted into large, well piled loaves, provided any deficiency in the rate of gas production is supplemented in a suitable manner.

Pratt (5) indicated that in a rather broad sense flour strength has been synonymous with flour quality. The presence or absence of strength factors governs the suitability of the flour for a specific end use. Strength is usually associated with wheat or flour protein and encompasses both quantity and quality measurements.

However, Blish (6) made a distinction between baking quality and baking strength. He viewed baking quality as the inherent or potential possibilities possessed by a flour, while baking strength implied both quality and a certain degree of tolerance to variations in baking treatment. Accordingly, a given flour can possess quality without strength, but not strength without quality. A flour which lacks strength, i.e., a weak flour can under circumstances be given such special treatment that a large loaf results, whereas under normal or unfavorable treatment it will not give good results. Flours of this type usually possess gluten proteins of high quality but in marginal quantities.

Blish and Sandstedt (7) felt that the protein content of flour was the only true index of baking strength and that variations in gluten quality could be compensated for by suitable adjustment in baking treatment.

Gortner and Doherty (8) found that glutens from strong flours had a greater hydration capacity than glutens from weak flours. They (8) attributed the difference between a strong and a weak gluten to the more perfect colloidal gel with highly pronounced physical-chemical properties formed by the strong gluten as compared with colloidal gel formed by weak gluten in which these properties are less pronounced.

Dough Formation and Structure

Hoseney (9) indicated that wheat flour is unique in its ability to form a dough when wetted with water and mixed. Both water and the application of mechanical energy are necessary to form wheat flour into dough. Mechanical energy or mixing is the process of converting flour and water into dough by both blending and distributing the dough ingredients and developing the gluten protein into a continuous phase (10). Mixing increases the dough's resistance to extension until a peak point is reached. This peak point is the mixing time of the flour. It has been also called the point of minimum mobility or optimum mixing time (10). Optimum bread cannot be produced if the dough is not mixed to that point. Continued mixing beyond optimum increases dough mobility and extensibility while it decreases dough consistency, the dough is broken down (10). The dough, thus formed, has the ability to trap and hold gas produced by panary fermentation and produce the light baked products we are all familiar with (9). Bennett and Ewart (11) indicated that microscopical studies of dough show clearly that starch granules are embeded in a protein matrix and it seems reasonable to infer that it is the latter which chiefly determines the rheological properties of dough.

It is generally believed that the gluten proteins of wheat are responsible for that unique property (9).

The gluten proteins are low in basic amino acids and high in glutamic acid (35% of the protein), thus more than 1 of every 3 amino acids in the protein is glutamic acid. The glutamic acid residue in the protein occurs as their amide, glutamine, rather than as free acids (9). The next most notable point about gluten's amino acid composition is the high level of proline (14%). Thus 1 of each 7 amino acid residues is involved in a ring structure; proline causes a kink in the protein chain (9). The remaining amino acids have a reasonable amount of amino acids with hydrophobic side chains and relatively low amounts of sulfur containing amino acids (9).

In general, the amino acid composition shows one-half of the protein made up of two amino acids (glutamine and proline) (9). The charge on the proteins is extremely low, with low levels of basic amino acids and practically all the acidic group occurring as their amide (9).

Wehrli and Pomeranz (12) indicated that the sequential arrangement of amino acids in a protein chain constitutes the first level of organization and is termed primary structure (12). The chains of amino acids are not straight but are folded to form characteristic three dimensional structures, called secondary structure. To account for the folding of the chains into relatively compact and rigid globular molecules, we visualize another level of organization, the teritary structure. Finally (12), if the protein consists of two or more loosely-linked globular sub-units, we speak of the quartenary or multimeric structure.

Why does the sequence of amino acids occupy such a prominent place in protein structure? The reason (12) is that once that sequence is given, the distances and bonds between individual amino acids and segments of protein chain are essentially determined. That brings us to the bonds that hold the polypeptide chains together.

Wehrli and Pomeranz (12) indicated that there are several types of covalent bonds in dough. They include bonds within the amino acids, between amino acids (peptide linkage) and disulfide links within or between peptide chains. The energy associated with (or required to break) those bonds is high. In addition, we have three types of non-covalent bonds that generally are much weaker than covalent bonds. These are the ionic, hydrogen and van der waals bonds. It must be emphasized that the four types of bonds are theoretical models that are useful in describing the natural bonds. The latter are never pure covalent, ionic, hydrogen or van der waals bonds, but always mixture of bonds. In addition to the four chemical bonds, there is the hydrophobic bond that is often confused with van der waals bond. Hydrophobic and van der waals has one thing in common, both are significant in reaction between non-polar groups. However, the hydrophobic bond is not a chemical bond but a thermodynamic phenomena or entrophy effect (12).

Finally (9) with the high amide groups and the low charge on the protein, we might suspect substantial hydrogen bonding in the system.

The Effects of Acids

Many workers have observed that the mechanical properties of wheat-flour dough are sensitive to changes in pH. For example, the addition of acid has been shown to increase the viscosity of flour suspension (13), reduce the extensibility of dough (14), and of gluten (15), increase the relaxation time of bromated and unbromated doughs (16) and to modify glutenin in a similar way to that brought about by fermentation (17).

Bennett and Ewart (11) studied the mechanism of the reaction of acids with flour protein by measuring the extensibility and resistance to extension of wheat-flour dough. They (11) investigated many different acids according to their strength by dissolving the desired quantity of these reagents in 2.5% aqueous sodium chloride. Their (11) study showed that there is a correlation between acid strength and power of reducing extensibility and it would seem likely that the main reaction of acids on flour proteins is to supply hydrogen ions. This would destroy the salt-linkages and cause the molecules to unfold by mutual repulsion of the positively charged side-groups and to take up a very extended configuration. This will lack the ability to yield which the coiled and linked system possessed (11).

Furthermore (11) the two parameters, extensibility (E) and resistance to extension (R) can give the product RE which gives an approximate indication of the true breaking stress and it is worthwhile to gain some additional information by examining the actual extensometer diagrams made by the same workers (11) which show that for a given family of curves at the same extension, the stress is proportional to the resistance. It was noticed that at the beginning of stretching, the stress in the acid-treated doughs was considerably increased compared with the control. This effect also can be observed from a paper by Schofield and Scott Blair (18). They (11) indicated that the molecule in an extended configuration will be able to form many more intermolecular hydrogen bonds in the acid-treated dough resulting in a stiffer three-dimensional network than in the control dough. The positively charged side-groups will be sufficiently far apart due to mutual repulsion that their weakening effect is greatly outweighed by the increased intermolecular hydrogen bonding. If, however, one considers the two doughs just before breaking point, the molecule in both cases will have assumed elongated configuration, induced by mutual repulsion of charged side-group in one case, and by mechanical deformation in the other.

The cohesion of the control dough will depend on hydrogen-bonding and salt links, whereas that of the acid-treated dough will depend on hydrogen-bonding only being in fact, lowered by the repulsion of the positively charged side-groups. Hence, the breaking stress will, in fact, be lower for acid-treated doughs (11).

Tanaka et al (19) studied the effects of organic and inorganic acids on dough at a fixed pH. Farinograph and Extensigraph curves indicated a considerable variation between the consistency of dough with organic acid and that with inorganic acid. At a fixed absorption the consistency of doughs containing organic acids increased with decreasing pH and gave weaker and more unstable doughs than did inorganic acids. It seems likely (19), that weak organic acids in their dissociated form combine with gluten and have a stronger effect on dough. The effect of strong acids (inorganic acids), including oxalic acid, is presumed to be brought about mainly by hydrogen ions, since they all have similar effects. Their type of curve (two peaks) is quite different from the organic acids except for the strong oxalic acid. The dibasic anions dissociated from sulfuric and oxalic acid should be considered in relation to this effect. Considering (19), the resistance and extensibility of the dough, the extensograms obtained with dough mixed with various acids can be classified into two groups. Those containing sulfuric acid, hydrochloric acid and oxalic acid show a little higher resistance than the organic acids and the control. The sulfuric acid and oxalic acid in this group indicated a lower extensibility than the other group, however, it is interesting that hydrochloric acid gave the highest extensibility in its group.

Although the above study (19) was undertaken to distinguish the effects of organic acid from those of inorganic acids on dough, it is obvious from the results, that the effect of acid on the physical properties of dough is presumed to progress under the influence of dissociated anionic residue and undissociated acid molecule as well as the hydrogen ion.

Tanaka et al (20) indicated that the mixing time rapidly increases for doughs mixed in air as the pH increases to 9 and rapidly decreases from pH 9 to pH 10. The farinograph stability of dough mixed in air increases with increases in pH from 4 to 9, and drops off sharply from pH 9 to 10.

They (20) found that dough produced at pH's of 4 or 10 were the least stable, had the shortest mixing times, and contained the greatest quantity of soluble proteins.

The Effects of Salts

Hlynka (21) studied the effect of salt on the absorption, consistency and dough development time, and showed that if dough consistency is held constant at 500 B.U., the effect of the first 0.25% salt is to decrease the absorption by 1.2% for the flour studied. The effect of subsequent increments of salt is somewhat less and tends to become linearly related to salt concentration. For 1% salt, the decrease in absorption was 2.3% and for 2% salt the decrease was 3%. Similarly (21) at constant absorption, the addition of salt decreases the consistency, at the 60% absorption level, salt concentration of 1 and 2% gave a decrease in consistency of 70 and 90 B.U., respectively. Concerning dough development time, he (21) studied this index when either the absorption or consistency was held constant, and the general effect of salt was to increase dough development time. For constant absorption, the effect of salt was to increase dough development time by about 1 minute for each 1% salt, and at constant consistency of 500 B.U. the effect of salt was to increase dough development time by about a half minute for each 1% salt.

A study by Galal et al (22) to simulate San Francisco sour dough French bread involved determining the effects of organic acids and salt on dough rheology. Regarding the effects of salt, they (22) observed a decrease in the rate of water absorption by the flour, an increase in arrival time and increase in dough stability when 1.5% salt was added.

Tanaka et al (20) indicated that with the extensigraph, salt has been known to increase both extensibility and resistance, except in the case of extensibility the increase is limited by the concentration of salt and at high concentrations, it falls to a lower level than the control.

The effect of salt is thought to be primarily due to changes in gluten hydration, and Bushuk and Hlynka (23) have explained this phenomenon by using the concepts of "free" and "bound" water. When salt is present in a dough system, it is thought to increase the amount of "free" or mobile water in the system by altering the gluten structure in such a way that the salt occupies the sites that were once occupied by the "bound" water. This theory supports and explains the decrease in water absorption that occurs with the addition of salt when the dough consistency is held constant and the toughening or strengthening effects of salt which result in longer dough development time (21).

Bennett and Ewart (24) studied the effects of sodium lactate and some other salts including sodium chloride on the extensometer curves of wheaten flour doughs and found that salt usually increases the breaking stress and reduces the extensibility. They (24) found that sodium lactate is more effective than sodium chloride and weaker flours showed the biggest change. They (24) also concluded that the action of the anions is probably more important than that of the sodium ions since the latter are a common factor in every additive. Anions tend to be preferentially absorbed compared with cations and anions which can cross-link by means of secondary forces appear to have more effect than the chloride ion (24). The lower protein flours or the weaker flour contain a higher proportion of salt-soluble proteins and these proteins contain more basic amino acids than the gluten proteins (25) and will more strongly adsorb anions thereby participating more fully in inter-chain bonding. Hence, doughs will have a higher breaking stress in the presence of salts as the proportion of salt-soluble protein increases, as the total protein content of the flour decreases (24).

The effect of the salts is generally to reveal differences between high and low protein flours, whereas no such divergence was found when acids were used (11). The acids destroyed salt linkages thereby removing one of the main causes of divergence in behavior between the two flours (24).

The Combined Effects of Acids and Salts

It is obvious from the preceding review that many investigators have studied the separate effects of salts and acids on the physical properties of wheat-flour doughs. However, only three references were found that dealt with the combined effects of acids and salts on dough rheology (11, 20, 26).

One of these references (11), has been discussed with some details early in this review, in which Bennett and Ewart investigated the action of acids on wheat-flour dough by dissolving the desired quantity of a reagent in 2.5% aqueous sodium chloride. Once again and briefly, they (11) indicated that the extensibility and breaking stress of dough containing both sodium chloride and acids decreased at low pH's. They (11) concluded that it would seem likely that the main reaction of acids on flour proteins is to supply hydrogen ions. This would destroy the salt linkages and cause the molecules to unfold by mutual repulsion of the positively charged side-groups and take up a very extended configuration.

Tanaka et al (20) by investigating the effect of acid and salt on the farinogram and extensigram of dough, indicated that the consistency of dough was increased by decreasing the pH with acetic acid in the absence of salt (sodium chloride), but contrarily, it tended to decrease from a lower value to the lowest in the presence of salt. With the extensigraph, the resistance showed a fixed lower level at the pH range 5.9 - 4.3 without salt, however, with salt it was increased from a low level to the highest value by decreasing the pH from 5.8 to 4.2. The extensibility showed a marked decrease in both cases with or without salt.

They (20) explained the high resistance of the extensigram brought about by the salt and the acid by the slight denaturation of gluten which brings inside polar group to the outside through unfolding, and which results in network formation. They (20) also indicated that the high resistance of the extensigram at low pH may also be caused by difficulties of the sulfhydryl disulfide exchange reaction as shown by Tsen (27).

A study by Galal et al (26) to investigate the effects of sodium chloride in combination with a mixture of some organic acids usually present in San Francisco sour dough on the physical properties of wheat-flour dough, they (26) indicated that these effects vary with the factor measured and/or the level of salt that was used. For example, compared to the control the water absorption of the flour decreased substantially when organic acid plus the salt were added to the flour and this was true regardless of the level of salt that was used. However, the decrease in water absorption with 1.5% NaCl was a little larger (5.6%) than with 1.0% salt (4.8%). These findings were unexpected because when these substances were used alone, the organic acids increased absorption and salt decreased absorption. Therefore, one might expect that the combination of acids plus salt would counteract the separate effects of each. The combination of organic acids plus salt also caused a tremendous increase in dough development time and dough stability.

They (26) concluded that the exact chemical reactions that are occurring when acids and salt are combined in a dough system are not known. However, they (26) presented a hypothesis to explain the action of salt on the behavior of dough at low pH which says that the effect of acid, as described before, is to increase the number of positively charged sites that are available for interactions with salt ions as well as exposing more hydrophobic groups. In addition, salt suppresses the intermolecular ionic repulsions, the exposed hydrophobic groups are freed to interact, and this, in turn, would result in a further strengthening of the protein structure. This great hydrophobic interaction would not exist if acid or salt were present separately. Eventually, the extremely insoluble protein increases the tendency to form very compact aggregates. Therefore, these reactions would explain the synergistic effects that were observed in their study (26) when the mixture of organic acids and salt were combined. Also the previously reported findings that the insoluble proteins impart strength to wheat-flour doughs while more soluble proteins have a weakening effect (28), further supports this interpretation.

Cysteine hydrochloride as an Additive

Henika et al (29) indicated that many cereal chemists have used cysteine and similar reducing agents in conventional doughs. These agents produced slack, runny doughs and made bread with low volume and poor grain quality. The more cysteine used, to a point, the faster the development, the greater the extensibility and the poorer the gas retention. They (29) indicated that in breads made from unbromated doughs loaf volume declined linearly with increasing cysteine.

While many authors described the effects of cysteine as deleterious (29, 30, 31), some others suggested that cysteine could improve the baking quality of bucky and long-mixing flour (32, 33). Read et al (32) indicated that normal bread flour does have relatively high content of protainase, which may be readily be set to work by the presence of some activating agent such as glutathione or cysteine hydrochloride. Many flours (32) give rise to doughs having glutens which show varying degrees of "buckiness." Doughs of this character are materially improved in baking quality by additions of suitable quantities of protease or of some activator for protease such as cysteine hydrochloride. Finney et al (33) indicated that dough extensibility and loaf volume of long-mixing flours were improved by cysteine hydrochloride.

It has been postulated that cysteine reduces the mixing time because it promotes sulflydryl-disulfide interchange reactions which accelerate dough development (27). Hoseney and Finney (10) indicated that increasing reducing agents such as cysteine reduces the mixing requirements. The degree that mixing time is decreased appears to depend on the amount of cysteine added rather than flour type. For example, 40 ppm of cysteine reduced mixing time by one-third regardless of original mixing time (33). These results (10, 33) are contrary to that indicated by Chamberlain et al (34) and Henika and Rodgers (35) that the response to added cysteine is influenced by the strength of the flour, strong flour responding more readily than weak flour.

Swanson and Andrews (36) indicated that mixogram patterns can be markedly changed by the use of certain substances. Cysteine decreases the time to reach minimum mobility, while aerosol OT (Sodium dioctylsulfosuccinate) produces opposite results. Thus, by controlling the amount of these reagents, the time factor in the mixogram pattern may be made longer or shorter. They (36) also indicated that when sodium chloride was combined with cysteine, the stiffening effect of NaCl still apparent but there were no increases in the time required to reach minimum mobility. It was mentioned before that loaf volume declined linearly with increasing cysteine in breads made from unbromated doughs (29). Meanwhile it was reported that at a certain level of bromate or any oxidizing agent in the dough, cysteine improved loaf volume and grain quality along with short mixing time (31, 35). It is suggested (32), that reduction and oxidation involve different factors in dough and their effects tend to counteract each other with respect to bread quality. The two effects thus counteract each other and when properly balanced will produce good volume and texture.

Finney et al (33) indicated that loaf volumes of a strong flour like Red River 68 were increased significantly by adding cysteine. The increase was attributed to increase dough extensibility. Crumb grains of cysteine-treated bread were equal or somewhat superior to grains in good control bread.

MATERIALS AND METHODS

Materials

Flour

The flours used were untreated hard and soft wheat flour. The hard wheat flour was Kansas State University flour with 10.6% protein and 39% ash (14% M.B.). Farinograph water absorption and mixing time were 58% and 3.5 minutes respectively. Mixograph mixing time was 4.5 minutes. Amylograph reading was 52 B.U. by adding .15 gram barley malt for 100 grams flour.

The soft wheat flour was prairie Rose 3606 supplied by Pillsbury Company with 9.73% protein and 39% ash (14% M.B.). Farinograph water absorption and mixing time were 53% and 2.5 minutes respectively. Mixograph mixing time was 3.5 minutes. Amylograph reading was 500 B.U. by adding .20 gram barley malt for 100 grams flour. These flour had a fairly short period of mixing and hence were suitable for use with substances which lengthen this time. Also these flours possess a weak characteristic on the Farinograms and mixograms primarily because they contain protein in marginal quantities.

Salt

The salt used was sodium chloride salt supplied by Fischer Scientific Company. This salt was dissolved in a distilled water and added as a solution with the desired concentrations. The pH of a 5% solution at 25^{o}C was 5.9.

Acid

The acid used was hydrochloric acid 2N solution supplied by Fischer Scientific Company. This acid was diluted by distilled water to obtain the desired amounts.

Cysteine

Cysteine was obtained from Sigma Chemical Company in the form of L-Cysteine hydrochloride.

Method

Physical dough testing

Two types of instruments were used to measure the physical characteristics of dough: the farinograph and the mixograph. Because each instrument has its advantages and disadvantages it was thought that a more accurate and complete picture of the physical characteristics of the doughs may be obtained by using the advantages from both instruments (38, 39).

The Farinograph AACC official method (40) was used to measure the water absorption of the flour used in the other physical dough measurements and in the baking tests.

The Mixograph AACC official method (41) employing a Swanson-Working mixograph revolving at approximately 100 rpm was used to measure the mixing time and stability of the doughs. The flour sample size that was used with this instrument was 10 grams (14% M.B.).

Two series of mixing experiments were run according to a statistical design (Tables 1 and 2). The first series was run under normal conditions in air. The second series was run under a nitrogen atmosphere to eliminate the oxidation of dough by air.

Baking Tests

A modified straight dough procedure was used to make a white pan bread (42). The only modification was incorporating and mixing the ingredients with the reagents under investigation to ensure constant yeast activity in all the batches with different treatment. All the ingredients except the yeast were incorporated with the desired amounts of acid and salt for one minute at low speed in Hobart A-200 Mixer. Then yeast was added and mixed with the rest of the dough for 30 seconds at the same speed. This procedure was being followed to prevent any direct contact between the yeast and both acid and salt. Doughs were mixed to the optimum development as determined by visual observation at high speed using the mixograph mixing time as a guide. At two-thirds of the mixograph mixing time an equivalent amount of sodium bicarbonate to acid was added to restore the pH of the dough to the original and a constant pH for all the batches with different treatments. At this point, it is worthwhile to mention that it was found that varying the pH over a wide range did not greatly influence the growth of yeasts in nutrient-rich media (43). The maximum growth and gas production for baker's yeast is between pH 4.0 and 5.5, and a drop in the pH to below 4 decreases its activity (44). However, we did not drop the pH of the dough below pH 4.8 before neutralizing the system by sodium bicarbonate. Therefore, we assumed that the addition of acid did not affect the yeast activity or gas production and this assumption was proved by checking the gassing power by the official AACC method 22-11 (45).

Differences in loaf volume and grain quality were due primarily to differences in gas retention, not gas production. The dough temperature after mixing was controlled to be 81 ± 1^{o}F. The doughs were divided immediately after mixing into two pieces (539 g. per piece) and rounded. Then, placed on greased pan and put into fermentation cabinet adjusted to 86^{o}F and 85% R.H. for 2½ hours. The dough punched, rounded and placed back on pan and into fermentation cabinet for 20 minutes. Then, moulded, panned and proofed to height (1.5 cm above pan) at 86^{o}F and 85% R.H. The doughs were baked at 425^{o}F for 25 minutes. The formula used was as follows: yeast 2.5%, sugar 6%, shortening 3%, SSL 0.25% milk replacer 2% on flour basis and enough barley malt to keep the amylograph reading at approximately 500 B.U. In case of using oxidant, potassium bromate was used at the optimum level for the control dough. Loaf volume and weight were measured immediately after baking. Loaf volume was determined by rapeseed displacement. Specific loaf volume was determined by dividing the volume by its weight (cc/g). The next day, loaves were cut and their crumb grain evaluated by this code. S = satisfactory, Q = questionable, and U to U_2 = unsatisfactory to extremely unsatisfactory.

Statistical Design and Analysis

Response surface methodology (RSM), which has been described by Cochran and Cox (46) and promoted by Henika and Henselman et al (47, 48) as a useful tool in food research, was used to investigate the combined effects of HCl and NaCl on some physical properties of dough and baking quality of the hard wheat flour. RSM involved use of a fractional experimental design along with a computer program to find a regression equation containing the desired response, in this case mixing time, stability, loaf volume, crumb characteristics and other dependent variables.

The independent variables were the amount of sodium chloride and hydrochloride acid. Each of these two variables were examined at five levels. Table (1) gives the variables and their levels. The two variables - five level fractional factorial design is given in Table (2). The measurement of the dependent variable was used as response input data (Y) and the regression coefficients were computed by the following quadratic response surface model

$$Y = B_0 + B_1x_1 + B_2x_2 + B_3x_1^2 + B_4x_1x_2 + B_5x_2^2 + E$$

Nonsignificant B values were eliminated by the computer program by a step wise regression procedure. The computer program supplied a coefficient of determination (R^2) for the original model and the final regression equation. This design assume that the different treatment combinations should be completely randomized.

This technique enabled us to achieve the following:

1. Predict the response for values of the treatment combinations that were not tested in the experiment.
2. The significance of the results and their level.
3. The significance of each term in the model and its level.
4. Determine which factor (independent variable) was more effective than the other.
5. Determine any interactions between the independent variables.

Table 1. Independent Variables and Their Levels for RSM Study

Independent Variables		Code Number for level				
		-2	-1	0	1	2
Sodium chloride[1]	X_1	.5	1	1.5	2.0	2.5
Hydrochloric acid[2]	X_2	5.0	10	15.0	20.0	25.0

[1] percentage on flour basis

[2] μ mole per gram flour

Table 2. RSM Design for Two Variables at Five Levels

Run number	Variables	
	X_1	X_2
0	1	--
1	-1	-1
2	1	-1
3	-1	1
4	1	1
5	$-\sqrt{2}$	0
6	$\sqrt{2}$	0
7	0	$-\sqrt{2}$
8	0	$\sqrt{2}$
9	0	0
10	0	0
11	0	0
12	0	0
13	0	0
14	-2	-2
15	2	2

X_1 = Sodium chloride

X_2 = Hydrochloric acid

6. Reproducibility of the experimental method by calculating the standard deviation.

Using Cysteine in Combination with Salt Plus Acid

In this series of experiments soft wheat flour was used, and it is worthwhile to mention that in many parts of the world, soft wheats with higher protein content are used for bread production (49). Many of the soft wheat varieties have good bread-making character, provided they contain sufficient protein. In New Zealand, there is only one type of wheat grown (a soft wheat) that gives satisfactory results for both bread and cookies (49). There is some work in the U.S. trying to develop such dual purpose wheats. If we are to develop a dual purpose wheat, it must be a soft wheat because low protein hard wheat will not produce good soft wheat products (49).

The same procedures for measuring the mixing time and stability were employed. Straight dough procedure with the same modifications was used. Cysteine added as ppm (flour basis) at the first step of mixing. Since it was found from the present study that when acid plus salt present in the dough there is no need for oxidizing agent, no oxidant was added to the formula. The salt was kept constant at 2% in all the treatment, considering the amount of salt formed in the dough due to the neutralization of HCl by sodium bicarbonate. The salt was kept constant at 2% because it is the regular amount usually present in the white pan bread and to ensure maximum constancy for yeast activity and gas production. The rest of the steps for baking and scoring the bread were the same as previously mentioned. The levels of acid used were 10, 20, and 30 μ mole per gram flour. Cysteine was used at levels of 20, 30, 40 and 50 ppm (flour basis).

Every treatment was at least experimentally duplicated and all the readings were analyzed statistically for significance and other purposes. The average for every treatment was used to plot the figures and tables.

RESULTS AND DISCUSSION

The Combined Effects on Mixing Time and Stability

It is well established that salt increases the mixing time and stability of dough (10, 21), and acid decreases both mixing time and stability (10, 20). Therefore, one might expect that the combination of acid plus salt would counteract the separate effects of each.

However, we found that any combination of acid plus salt increased mixing time (Fig. 1) and stability (Fig. 2). Both mixing time and stability were increased by increasing both acid and salt. At a constant amount of salt (2%), increasing amounts of acid increased both mixing time and stability (Table 4). Mixing time increased by more than 100% when 40 μ mole acid were added (Table 4, Fig. 3). By increasing either the acid or salt and decreasing the other, it was possible to obtain the same mixing time. For example (Fig. 4, Table 3) adding 2% salt (control) gave a 6 min. mixing time, by decreasing the amount of salt to 1% and adding 10 μ mole acid, it was possible to obtain the same mixing time (6 min.). Also 2% salt plus 20 μ mole acid, 2.2% salt plus 15 μ mole acid and 1.5% salt plus 22 μ mole acid gave the same mixing time (8.5 min). It seems that these combinations provide for a complementary action on mixing time. All these mixings were done under normal conditions in air.

Similar results were obtained when dough mixing was done under a nitrogen atmosphere (Table 4). There were no differences in mixing time and stability, when doughs were mixed in either air or nitrogen. This indicates that the increase in mixing time and stability was due to the combined effects of acid plus salt and not to any oxidation reaction.

Statistically, the results were very significant (0.0001 level for mixing time and 0.0002 for stability). Both acid and salt were needed to give those significant results. However, in the case of mixing time both salt and acid

Figure 1. Mixing time as affected by different combinations of HCl and $NaCl$.

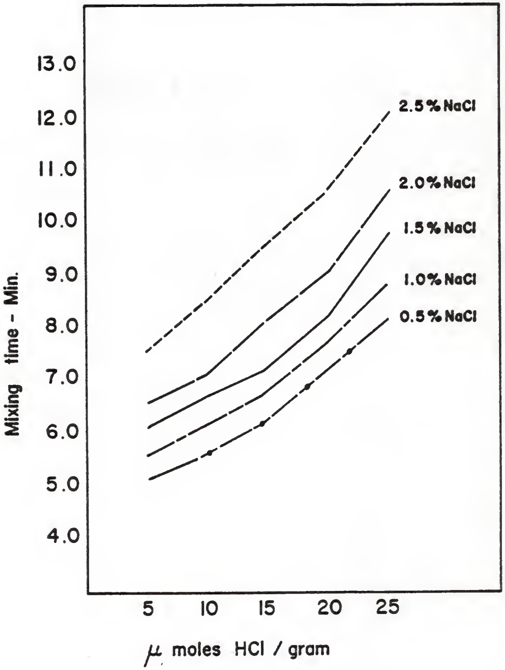

2.5% NaCl
2.0% NaCl
1.5% NaCl
1.0% NaCl
0.5% NaCl
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
Mixing time - Min.
5
10
15
20
25
μ moles HCl / gram

Figure 2. Stability as affected by different combinations of HCl and NaCl.

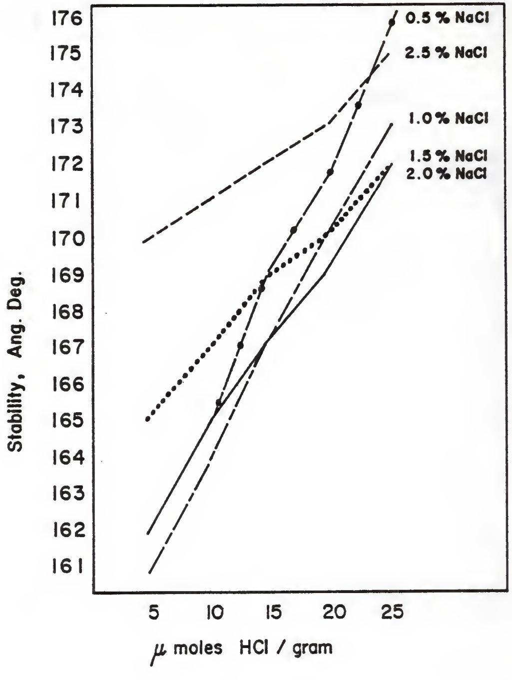

176
175
174
173
172
171
170
169
168
167
166
165
164
163
162
161
Stability, Ang. Deg.
0.5 % NaCl
2.5 % NaCl
1.0 % NaCl
1.5 % NaCl
2.0 % NaCl
5
10
15
20
25
μ moles HCl / gram

Table 3. The combined effects of NaCl and HCl on the physical properties of dough and baking quality[a]

Treatment No.	Addition		Mixing Time	Stability	Loaf Volume[b]		Crumb Characteristics		Loaf Symmetry	
	Salt	Acid			Without[c]	With[d]	Without[c]	With[d]	Without[c]	With[d]
C	2.0	---	6.0	163	5.83	6.49	S	S	Regular	Round corner
1	1.0	10.0	6.0	163	5.85	5.93	Q	Q	"	"
2	2.0	10.0	7.0	166	5.97	5.53	S	U_1	"	"
3	1.0	20.0	7.5	170	5.79	4.16	U	U	"	"
4	2.0	20.0	8.5	171	5.76	5.57	U	U_1	"	"
5	0.79	15.0	6.0	168	5.74	4.35	U_1	U_2	"	"
6	2.21	15.0	8.5	171	5.54	5.16	U	U_2	"	"
7	1.5	7.9	6.0	167	5.89	5.78	Q	Q	"	"
8	1.5	22.1	8.5	171	5.08	5.52	U	U_1	"	"
9	1.5	15.0	7.0	166	5.64	5.22	Q	U_1	"	"
10	0.5	5.0	5.0	162	5.52	5.23	U	U	Sharp corner	"
11	2.5	25.0	12.0	174	4.33	4.13	U	U_2	Round corner	"

[a] Combinations according to statistical design
[b] Specific loaf volume (cc/g)
[c] Without oxidant in the dough
[d] With oxidant in the dough

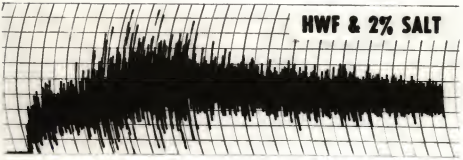
S = Satisfactory
Q = Questionable
U to U_2 = Unsatisfactory to extremely Unsatisfactory

Table 4. Mixing time and stability as affected by the amount of HCl added at 2% salt level (flour basis)

HCl µ mole/g	Mixing Time		Stability[1]	
	Air	Nitrogen	Air	Nitrogen
--	6.0	6.0	163	163
10	7.0	7.0	166	166
20	8.5	8.5	171	171
30	11.5	11.5	172	172
40	15.0	15.0	174	174

[1]Stability measured as the angle degree between the ascending and descending slopes

Figure 3. Effect of HCl in the presence of NaCl on mixograph mixing time of hard wheat flour


HWF & 2% SALT

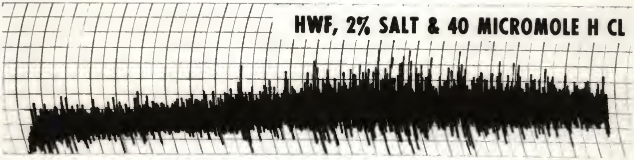

HWF, 2% SALT & 40 MICROMOLE H CL

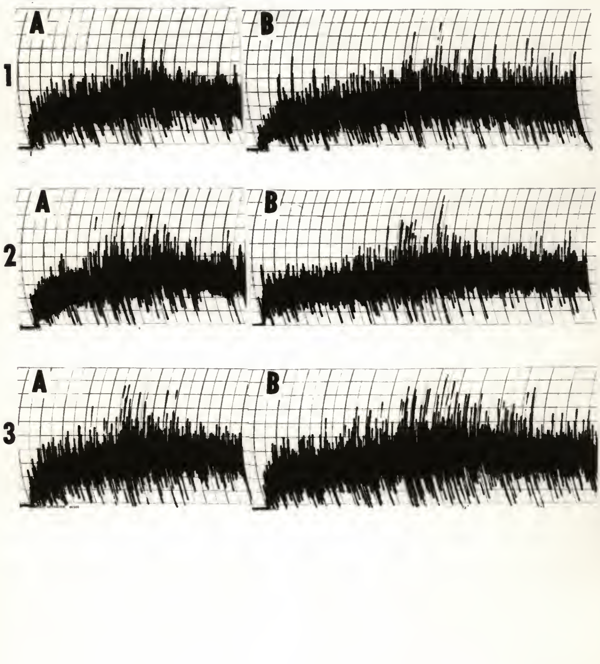
Figure 4. Effect of different combinations from NaCl and HCl on mixograms

Line \ Column	A	B
1	0 + 2.0	20 + 2.0
2	10 + 1.0	15 + 2.2
3	7.9 + 1.5	22 + 1.5

All the mixograms in Column A have the same mixing time (6 min)

All the mixograms in Column B have the same mixing time (8.5 min)

The first figure in each Column represents the amount of HCl as μ mole per gram flour, the second figure represents the amount of NaCl as a percentage (flour basis)


A
B
1
A
B
2
A
B
3

were found equally effective, but acid was found more effective on stability than salt.

From the preceding review and results, it seems reasonable to suggest that there was a synergistic effect on mixing time and stability when acid plus salt were combined in the dough.

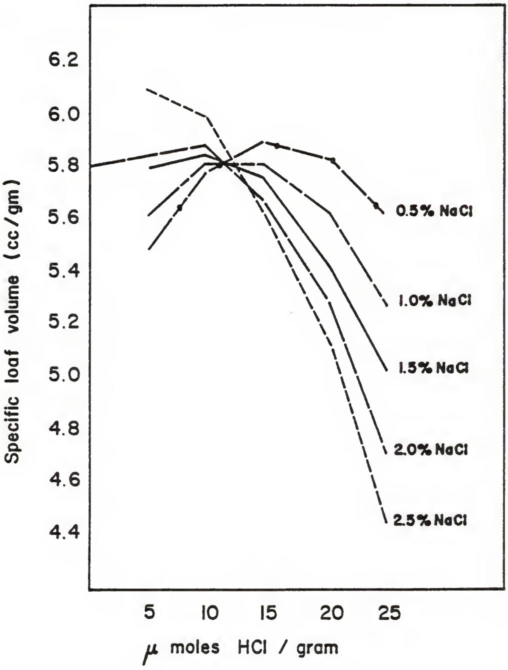
The exact chemical reactions that are occurring when acids and salt are combined in a dough system are not known (26). However, some workers (20, 26) presented some explanations to the action of salt on the behavior of dough at low pH. All based on changes occurring in the protein structure. The gluten protein fractions govern the quality factors of mixing time and loaf volume (50, 51). Water-insoluble fraction (glutenin) has long mixing requirement, whereas the addition of water-soluble (gliadins) markedly shorten the mixing requirements. Salt soluble fractions (albumin and globulin) have little effect upon mixing characteristics (52). Short mixing flour contained more water-soluble protein initially and more is produced during mixing (52, 53).

Tanaka et al (20) and Galal et al (26) postulated that the combined effects of salt plus acid result in a very compact and insoluble protein aggregate. Smith and Mullin (52) indicated that the additives which decrease protein solubility markedly increase mixing requirement. Also, Kasadara et al (28) indicated that the insoluble proteins impart strength to wheat flour doughs while more soluble proteins have a weakening effect. From the previous investigations and our results, it seems reasonable to conclude that the synergistic effect of acid plus salt on the flour is a strengthening effect.

The Combined Effects on Loaf Volume and Other Characteristics

Figure (5) shows the combined effects on loaf volume without oxidant in the formula. Loaf volume increased with various level of salt as the amount of acid increased to a certain level then starts to decrease. Loaf volume

Figure 5. Specific loaf volume as affected by different combinations of HCl and NaCl without oxidant in the formula.

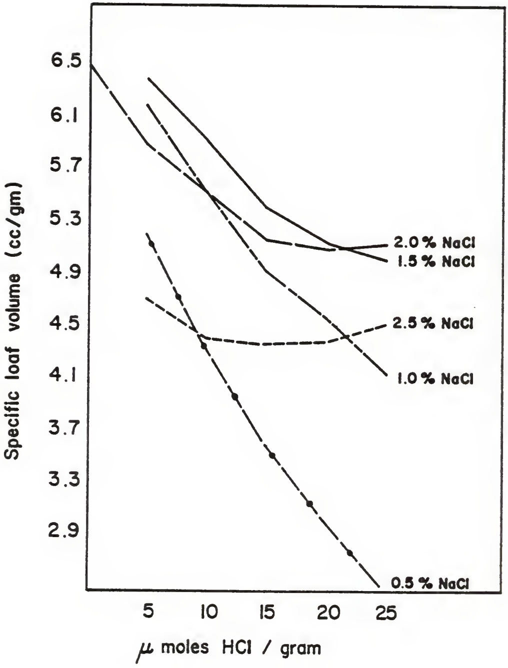

6.2
6.0
5.8
5.6
5.4
5.2
5.0
4.8
4.6
4.4
Specific loaf volume (cc/gm)
0.5% NaCl
1.0% NaCl
1.5% NaCl
2.0% NaCl
2.5% NaCl
5
10
15
20
25
μ moles HCl / gram

had a small peak at acid level of 5 μ mole with 2.5% salt, 10 μ mole with 1.0%, 1.5% and 2% salt and 15 μ mole with .5% salt. At high level of salt, a small amount of acid needed to obtain this peak and vise versa. These results provide and explain a complementary action by acid and salt on loaf volume. Above 15 μ mole acid, loaf volume decreased with all levels of salt. The loaves obtained from doughs treated with 25 μ mole acid and 2.5% salt were the least in volume with round corner.

Figure (6) shows the combined effect on loaf volume with the optimum level of oxidant in the formula. Loaf volume decreased when acid was increased at all levels of salt. There was no increase in loaf volume at any combination of salt plus acid. All the bread characterized by round corner (Table 3). It is assumed that all these bread made from over oxidized dough. Table (3) shows that the combinations of 2% salt without acid and 1% salt with 10 μ mole acid when used with the optimum level of oxidant gave larger volumes than without oxidant. At higher levels of acids or salts the loaf volume decreased by using oxidized dough than unoxidized dough. Table (3) and Figure (5) show that there is a slight increase in loaf volume (5.97) than the control (5.83) when 10 μ mole acid were used with 2% salt and without oxidant in the formula. However, when the optimum level of oxidant was used with 2% salt a large loaf volume (6.49) was obtained. The oxidant gave better loaf volume than any combination of salt plus acid. In general when oxidant used in combination with salt plus acid, loaf volume decreased with a characteristic of over oxidized dough.

Statistically, the combined effect on loaf volume was significant at level 0.001. Although, the correlation between the treatment and crumb characteristics was low, the largest loaf volume had the best crumb characteristics. No meaningful correlation was found between the treatments and other bread characteristics such as break and shred or crust color.

Figure 6. Specific loaf volume as affected by different combinations of HCl and NaCl with oxidant in the formula.


6.5
6.1
5.7
5.3
4.9
4.5
4.1
3.7
3.3
2.9
Specific loaf volume (cc/gm)
2.0 % NaCl
1.5 % NaCl
2.5 % NaCl
1.0 % NaCl
0.5 % NaCl
5
10
15
20
25
μ moles HCl / gram

If as postulated by Tanaka et al (20) that any combination of acid and salt used in their study markedly increased the resistance and decreased the extensibility of the wheat flour dough with the extensigraph and by Bennett and Ewart (10) that extensibility and resistance had a small peak of increment at acid level lower than 10 mM of acetic acid per 280 g. flour in 2.5% sodium chloride solution with the Simon research extensometer.

It is suggested that these two properties (resistance to extension and extensibility of the dough) responsible for the preceding results (Figs. 5 and 6). Desirable or good doughs must show sufficient resistance to extension to retain gas cells and prevent their escape or accumulation at their tops and also show enough extensibility so the gas cells can expand during proof time without any rupture of the membranes between them. This means that gas retention depends on a balance between these two properties (54). It is clear that the treatment with acid plus salt affect this balance. It seems reasonable to infer that the slight increase in loaf volume at low levels of acid is due to increase in the resistance with a relatively enough extensibility to achieve this balance, but at high levels the resistance and extensibility are far away to achieve this balance.

In this manner the combined effects of acid and salt similar to that of oxidizing agents, optimum amounts of oxidizing agents improve gas retention and loaf volume, whereas larger amounts decrease gas retention and loaf volume. With increasing oxidation levels the dough becomes more and more rigid. For most flours this increase in rigidity is desirable. After the proper balance of these two properties has been attained a further increase in rigidity reduces gas retention and loaf volume (54).

It is therefore concluded that if acid plus salt were present in the formula, then no oxidant would be required, and this is due to the marked strengthening effect that is produced by these two reagents.

The Combined Effects of Salt and Acid in the Presence of Cysteine

It is obvious from the preceding results and discussion that salt plus acid increased mixing time, stability and slightly increased the loaf volume at low level of acid without oxidant in the formula and decreased loaf volume when oxidant was present in the formula. Both salt and acid were found equally effective on mixing time. Acid was found more effective than salt on stability and loaf volume. The effect on loaf volume was discussed through the relation between loaf volume and its physical dough properties. Salt plus acid increased the resistance to extension and decreased the extensibility of the dough (20). All these findings justified the use of cysteine hydrochloride in combination with salt plus acid to examine the combined effects on flour strength by another approach.

The Combined Effect on Mixing Time and Stability

In general as mixing time increases dough extensibility decreases and dough stability, elasticity, and mixing tolerance increase (55).

Doughs with short mixing time usually have a predominance of extensibility and insufficient elasticity for a stable dough, whereas doughs having unusually long mixing times generally are not extensible enough to be desirable elastic. Both very short and extremely long mixing times, therefore are undesirable properties (55).

The results (Fig. 7 and Table 5) indicated that increasing the amount of cysteine at any level of acid decreases mixing time. These results are in agreement with the literature reviewed (10, 27, 33, 34, 35, 36).

Increasing the amount of acid (in the presence of salt) at any level of cysteine, increased the mixing time. Thus, by a suitable choice of the amounts of these reagents, the time factor in the mixogram pattern may be made longer or shorter (Fig. 8).

Figure 7. Mixing time as affected by combinations of Hydrochloric acid and Cysteine at 2% salt.

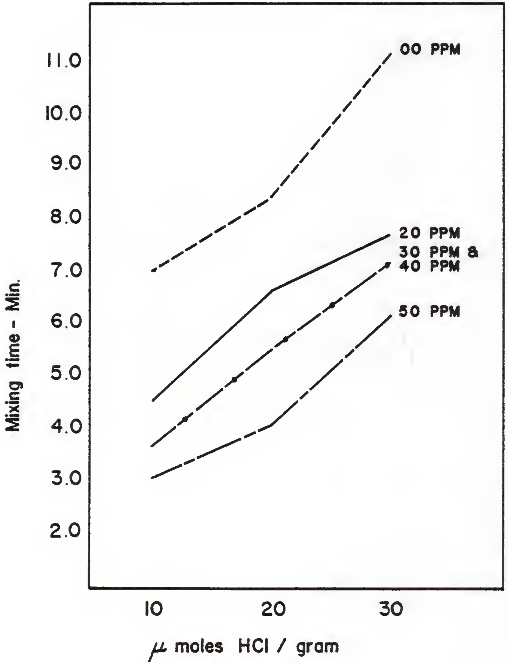

00 PPM
20 PPM
30 PPM &
40 PPM
50 PPM
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
Mixing time - Min.
10
20
30
μ moles HCl / gram

Table 5. The combined effect of HCl and cysteine with 2% NaCl in the dough on mixing time (minutes)

HCl^2 \ $Cysteine^1$	00	20	30	40	50
10	6.5	4.5	3.5	3.5	3.0
20	8.0	6.5	5.5	5.5	4.0
30	11.0	7.5	7.0	7.0	6.0

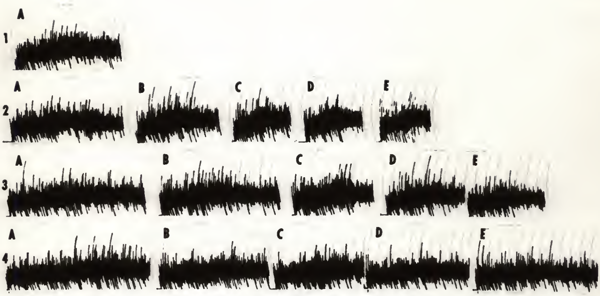
[1] Cysteine added as ppm (flour basis)

[2] HCl added as μ mole per gram flour

Figure 8. Effect of cysteine in combination with hydrochloride acid plus 2% sodium chloride on mixograph mixing time

Line \ Column	A	B	C	D	E
1	0 + 0				
2	10 + 0	10 + 20	10 + 30	10 + 40	10 + 50
3	20 + 0	20 + 20	20 + 30	20 + 40	20 + 50
4	30 + 0	30 + 20	30 + 30	30 + 40	30 + 50

The first figure in each Column represents the amount of HCL as μ mole per gram flour, the second figure represents the amount of cysteine as ppm (flour basis)


A
1
A
B
C
D
E
2
A
B
C
D
E
3
A
B
C
D
E
4

At the levels of 30 and 40 ppm cysteine, there is no change in mixing time, and it seems that the cysteine required to saturate the development reactions is quite constant, regardless of differences in stiffness of the dough or the amount of acid added to the dough in the presence of salt.

It seems likely from Figure (7) and Table (5) to indicate that the degree that mixing time is decreased depends on the amount of cysteine added rather than the strength or the type of flour. These results can be supported by what previously reported by Hoseney and Finney (10) and Finney (33), and contrary to what was indicated by Chamberlen et al (34) and Henika and Rodgers (35).

If as postulated by Swanson et al (36) that when NaCl was combined with cysteine there were no increase in the time required to reach minimum mobility, it seems reasonable to infer that salt alone and in combination with acid differ in their function on mixing time. This interpretation may further support the previous finding in this study that the combined effect of acid and salt is a synergistic and strengthening effect.

In general, flours with longer mixing times will have greater mixing tolerance. Mixing time and mixing tolerance (stability) are interrelated (49). The main effect of cysteine is shortening of the developing and the weakening periods as shown by steeper ascending and descending slopes of the mixogram patterns (36).

The results (Fig. 9 and Table 6) indicated that increasing the amount of cysteine at any level of acid decreases the stability of the dough. At any level of cysteine increasing the amount of acid (in the presence of salt) increases the stability of the dough.

These results are in complete agreement with the above statements and the literature reviewed (36, 49, 55).

Figure 9. Stability of dough as affected by combinations of Hydrochloric acid and Cysteine at 2% salt.

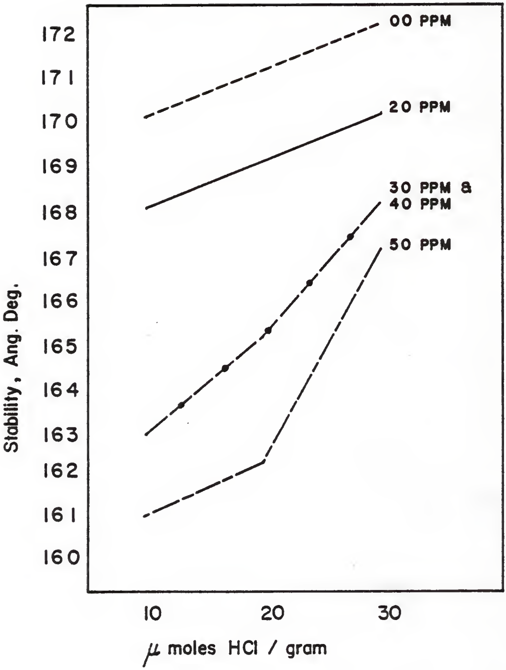

172
171
170
169
168
167
166
165
164
163
162
161
160
Stability, Ang. Deg.
00 PPM
20 PPM
30 PPM &
40 PPM
50 PPM
10
20
30
μ moles HCl / gram

Table 6. The combined effect of HCl and cysteine with 2% NaCl in the dough on stability[3]

HCl[2] \ Cysteine[1]	00	20	30	40	50
10	170	168	163	163	161
20	171	169	165	165	162
30	172	170	168	168	167

[1] Cysteine added as ppm (flour basis)

[2] HCl added as μ mole per gram flour

[3] Stability measured as the angle degree between the ascending and descending slopes

It seemed reasonable to expect that if reducing matter in the dough were oxidized its effects in mixing and stability would be eliminated. This was not the case (Fig. 7 and Fig. 9). Therefore it would be concluded that neither acid nor salt have an effect on cysteine oxidation.

Statistically, it was found that the treatments have a significant effect on mixing time and stability. By using stepwise regression procedure, the most model fit the data did not include the term acid by cysteine. This revealed that cysteine and acid in the presence of salt does not interact, i.e. their effects on mixing time and stability are independent of each other.

The Combined Effect on Loaf Volume and Other Characteristics

Many authors described the effects of cysteine in conventional breadmaking as deleterious (29, 30, 31). For example Henika et al (29) indicated that in breads made from unbromated doughs, loaf volume declined linearly with increasing cysteine.

Some others suggested that cysteine could improve the baking quality of bucky and long mixing flour (32, 33).

Meanwhile it was reported (31, 35) that at a certain level of bromate or any oxidizing agent in the dough, cysteine improved loaf volume and grain quality along with short mixing time.

Cysteine improves the baking performance of strong flour (56). The improvement was attributed to increase dough extensibility (33).

From the above brief review, it is obvious that cysteine gives its improvement effects only when used with bucky or strong flour.

The results presented in Figure (10) and Table (7) indicated that at any level of acid increasing the amount of cysteine to a certain level (40 ppm) increases loaf volume. Increasing the amount of cysteine above that level decreases loaf volume. The increase in loaf volume by adding cysteine up to 40 ppm is due to increased and improved dough extensibility. Above that level dough becomes slacky and more extensible, so the cells expand more readily and become porous, lose gas and finally break. Thus, the gas retention and loaf volume decreases. It is important, both theoretically and practically, that the cysteine level which improved the extensibility was only slightly higher than the level which effectively reduced mixing time (Table 5) and (Fig. 10). At any level of cysteine increasing the amount of acid decreases loaf volume. This probably is due to the increase in resistance and decrease in extensibility as mentioned earlier in this study (20). It is obvious that the optimum level of cysteine (40 ppm) gives the largest loaf volumes in all the treatments regardless of differences in the amount of acid added or the stiffness of the dough. It seems that the amount of cysteine required to improve the extensibility of the dough is quite constant regardless of the stiffness or the strength of the dough. The degree at which the extensibility was improved depends on dough strength. This explains why the largest loaf volumes were obtained at 10 μ mole acid level with different levels of cysteine (Fig. 10).

A similar result with different cysteine and bromate levels were reported by Henika and Rodgers (35). They (35) used bromate with cysteine to improve the loaf volume and grain quality.

The similar improvement effects of cysteine on dough treated with acid plus salt with that treated by bromate (31, 35) or made from strong flour (33, 56) would, further support the previous findings in this study that the combined effect of acid and salt is a synergistic and strengthening effect.

The best loaf volume and grain quality along with short mising time were obtained with 40 ppm cysteine and 10 μ mole acid (Fig. 11).

Statistically, loaf volume significantly affected by the treatments. Even though the correlation between the treatments and crumb characteristics

Figure 10. Specific loaf volume as affected by different combinations of HCl and Cysteine at 2% salt.

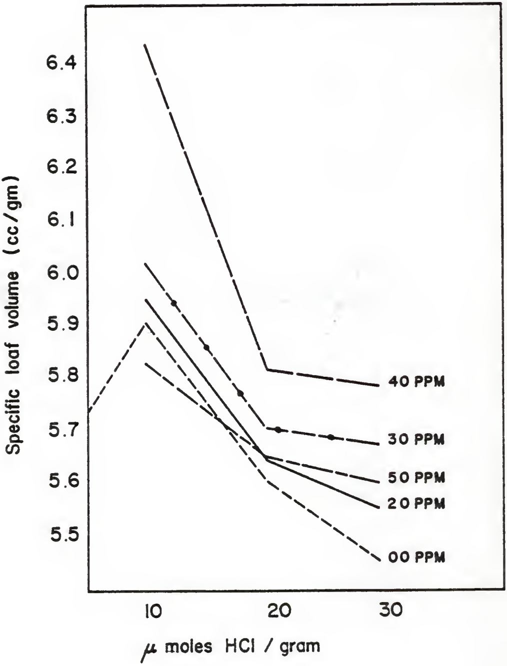

6.4
6.3
6.2
6.1
6.0
5.9
5.8
5.7
5.6
5.5
Specific loaf volume (cc/gm)
40 PPM
30 PPM
50 PPM
20 PPM
00 PPM
10
20
30
μ moles HCl / gram

Table 7. The combined effect of HCl and cysteine with 2% NaCl in the dough on specific loaf volume[3] (cc/g.)

HCl[2] \ Cysteine[1]	00	20	30	40	50
10	5.92	5.94	6.02	6.42	5.83
20	5.61	5.63	5.69	5.8	5.64
30	5.51	5.56	5.63	5.77	5.61

[1] Cysteine added as ppm (flour basis)

[2] HCl added as μ mole per gram flour

[3] The average of four loaves made from two batches

was low, the largest loaf volume had the best crumb characteristics (Table 8). No meaningful correlation could be found between the treatments and break and shred, and proof time (Table 8).

Reduction and strengthening the dough probably involve different factors in dough and their effects tend to counteract each other with respect to bread quality. The two effects thus counteract each other and when properly balanced will produce good volume and grain.

If a dough improver is defined as an ingredient which significantly improves loaf volume and grain quality (35) then under these conditions, both cysteine and a combination of HCl and NaCl should be called dough improvers.

Figure 11. Cut loaves baked from soft wheat flour with 2% salt (control) and with a combination of 10 μ mole HCl and 40 ppm cysteine plus 2% salt


10 MICROMOLE ACID
& 40 PPM CYSTEINE
CONTROL

Table 8. The combined effect of acid and salt (2%) with cysteine on bread quality

Treatment No.	Treatment		Sp. Loaf Volume	Crumb Characteristics	Break and Shred	Proof Time Minutes
	Acid[a]	Cysteine[b]				
o	--	--	5.77	Q	U_2	110
1	10	--	5.92	Q	Q	97
2	10	20	5.94	Q	U_2	96
3	10	30	6.02	Q	U_2	90
4	10	40	6.42	S	S	84
5	10	50	5.83	Q	U_1	80
6	20	--	5.61	Q	U_2	100
7	20	20	5.63	Q	U_2	100
8	20	30	5.69	U_2	U_1	94
9	20	40	5.80	Q	U	95
10	20	50	5.64	Q	U	93
11	30	--	5.51	Q	U_2	85
12	30	20	5.56	Q	U_2	85
13	30	30	5.63	Q	U	84
14	30	40	5.77	Q	Q	83
15	30	50	5.61	Q	S	80

[a] Added as µ mole per gram flour

[b] Added as ppm (flour basis)

S = Satisfactory

Q = Questionable

U - U_2 = Unsatisfactory to extremely unsatisfactory

SUMMARY

This study showed that:

1. The combination of salt plus acid strengthened the flour as measured by the increase in mixing time and stability.
2. Salt and acid have a synergistic effect on strengthening the flour.
3. Loaf volume has a small peak of increments at low levels of either the salt or the acid when combined in unoxidized dough.
4. When the optimum oxidized dough is treated by any combination of salt plus acid, a characteristic of overoxidized dough appeared and a decrease in loaf volume obtained.
5. If salt plus acid are present in the dough, then no oxidant would be required and this was due to the marked strengthening effect that is produced by these two reagents.
6. The combined effect of salt plus acid on the balance between resistance to extension and extensibility of the dough is very important in determining loaf volume and crumb characteristics.
7. Cysteine hydrochloride in combination with salt plus acid, greatly improve the balance between resistance to extension and extensibility of the dough, thus the strengthening effects of the salt plus acid are more pronounced as measured by loaf volume potential.
8. The cysteine required to saturate the development reactions is quite constant regardless of differences in stiffness or strength of the dough.
9. The degree that mixing time is decreased depends on the amount of cysteine added rather than the strength or the type of flour.
10. The amount of cysteine required to improve the extensibility of the dough is quite constant regardless of the stiffness or the strength of the

dough. The degree at which the extensibility is improved depends on dough strength.

11. The cysteine level which improves the extensibility is only slightly higher than the level which effectively reduced mixing time.
12. A combination of 10 μ mole HCl, 40 ppm cysteine and 2% salt gives the best loaf volume and grain quality along with short mixing time. Thus both cysteine and a combination of HCl and NaCl should be called dough improvers.

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APPENDIX

Table 1A. The combined effects of different combinations from HCL and NaCl on the physical properties of dough and baking quality without oxidant in the formula

TN	SALT	ACID	MT	ST	LV	CMB	BR	PT	CST	pH	GP
0	2.00	0.0	6.0	163	5.83	5	3	106	3	5.10	470
1	1.00	10.0	6.0	163	5.85	4	3	93	2	5.34	475
2	2.00	10.0	7.0	166	5.97	5	4	109	2	5.23	465
3	1.00	20.0	7.5	170	5.79	3	3	108	2	5.26	475
4	2.00	20.0	8.5	171	5.76	3	3	112	2	5.40	475
5	0.79	15.0	6.0	168	5.74	2	3	102	2	5.24	460
6	2.21	15.0	8.5	171	5.54	3	2	122	3	5.35	450
7	1.50	7.9	6.0	167	5.89	4	3	106	3	5.35	465
8	1.50	22.1	8.5	171	5.08	3	1	100	2	5.08	470
9	1.50	15.0	7.0	166	5.66	4	2	102	2	5.27	470
10	1.50	15.0	7.0	166	5.65	3	2	102	2	5.25	460
11	1.50	15.0	7.0	166	5.63	4	2	102	2	5.23	475
12	1.50	15.0	7.0	166	5.62	4	2	102	2	5.26	470
13	1.50	15.0	7.0	166	5.64	4	2	101	2	5.26	460
14	0.50	5.0	5.0	162	5.52	3	1	82	1	4.97	550
15	2.50	25.0	12.0	174	4.33	3	1	107	2	5.32	355

TN = Treatment number

MT = Mixing time/min

ST = Stability/angle degree

LV = Specific loaf volume

CMB = crumb characteristics

BR = Break and shred

PT = Proof time/min

CST = Crust color

GP = Gassing power

Table 2A. The combined effects of different combinations from HCl and NaCl on the physical properties of dough and baking quality with oxidant in the formula.

TN	SALT	ACID	MT	ST	LV	CMB	BR	PT	CST
0	2.00	0.0	6.0	163	6.49	5	5	76	5
1	1.00	10.0	6.0	163	5.93	4	4	85	5
2	2.00	10.0	7.0	166	5.53	2	3	69	4
3	1.00	20.0	7.5	170	4.16	3	1	76	3
4	2.00	20.0	8.5	171	5.57	2	3	76	3
5	0.79	15.0	6.0	168	4.35	1	1	85	3
6	2.21	15.0	8.5	171	5.16	1	2	61	4
7	1.50	7.9	6.0	167	5.78	4	3	85	4
8	1.50	22.1	8.5	171	5.52	2	2	82	2
9	1.50	15.0	7.0	166	5.21	1	2	70	4
10	1.50	15.0	7.0	166	5.24	2	2	71	4
11	1.50	15.0	7.0	166	5.22	2	2	71	4
12	1.50	15.0	7.0	166	5.25	2	2	72	4
13	1.50	15.0	7.0	166	5.21	2	2	72	4
14	0.50	5.0	5.0	162	5.23	3	2	69	1
15	2.50	25.0	12.0	174	4.13	1	1	92	4

TN = Treatment number

MT = Mixing time/min

ST = Stability/angle degree

LV = Specific loaf volume

CMB = Crumb characteristics

BR = Break and shred

PT = Proof time/min

CST = Crust color

Table 3A. The combined effects of different combinations from cysteine and HCl with 2% NaCl on the physical properties of dough and baking quality.

TN	CYS	ACID	MT1	MT2	ST1	ST2	LV1	LV2	CRUMB	BR	PT
0	0	0	5.0	5.0	165	165	5.80	5.74	4	1	110
1	0	10	7.0	7.0	170	170	5.93	5.91	4	4	97
2	20	10	4.0	4.5	168	168	5.95	5.92	4	1	96
3	30	10	3.5	3.5	163	163	6.00	6.05	4	1	90
4	40	10	3.5	3.5	162	162	6.43	6.40	5	5	84
5	50	10	3.0	3.0	161	161	5.85	5.80	4	2	80
6	0	20	8.5	8.5	171	171	5.62	5.60	4	1	100
7	20	20	6.5	6.5	169	169	5.65	5.61	4	1	100
8	30	20	5.5	5.5	166	166	5.72	5.65	1	2	94
9	40	20	5.5	5.5	164	164	5.88	5.72	4	3	95
10	50	20	4.0	4.0	162	162	5.70	5.63	4	3	93
11	0	30	11.0	11.0	172	172	5.52	5.50	4	1	85
12	20	30	7.5	7.5	170	170	5.55	5.57	4	1	85
13	30	30	7.0	7.0	169	169	5.65	5.60	4	3	84
14	40	30	7.0	7.0	168	168	5.82	5.71	4	4	83
15	50	30	6.0	6.5	167	167	5.60	5.63	4	5	80

TN = Treatment number

CYS = Amount of cysteine hydrochloride as ppm

ACID = Amount of HCL as μ moles/g. flour

MT = Mixing time/min

ST = Stability/angle degree

LV = Specific loaf volume

CRUMB = Crumb characteristics

BR = Break and shred

PT = Proof time/min

Figure 1A. Contour plot of the mixing time at varying levels of HCL and NaCl

(A = 5, B = 6, C = 7, D = 8, E = 9, F = 10, G = 11, H = 12)

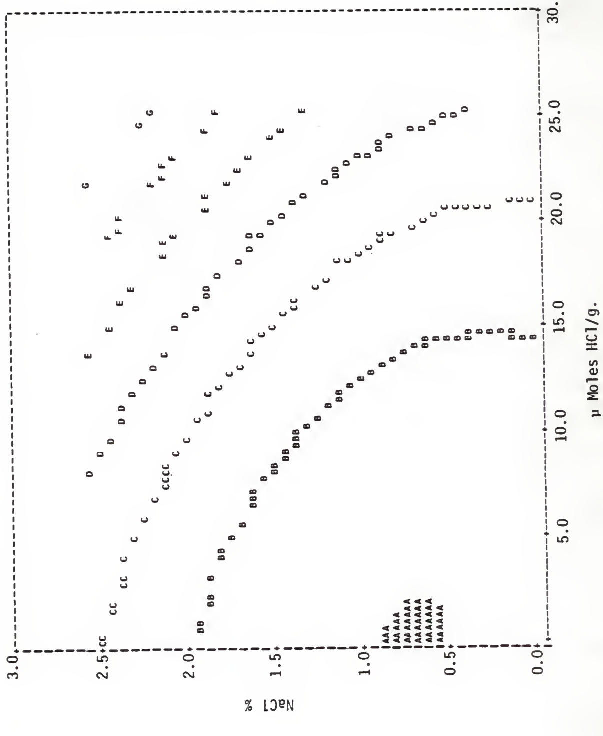

NaCl %
µ Moles HCl/g.
0.0
0.5
1.0
1.5
2.0
2.5
3.0
5.0
10.0
15.0
20.0
25.0
30.0

Figure 2A. Contour plot of the stability at varying levels of HCL and NaCl
(A = 162, B = 164, C = 166, D = 168, E = 170, F = 172, G = 174)

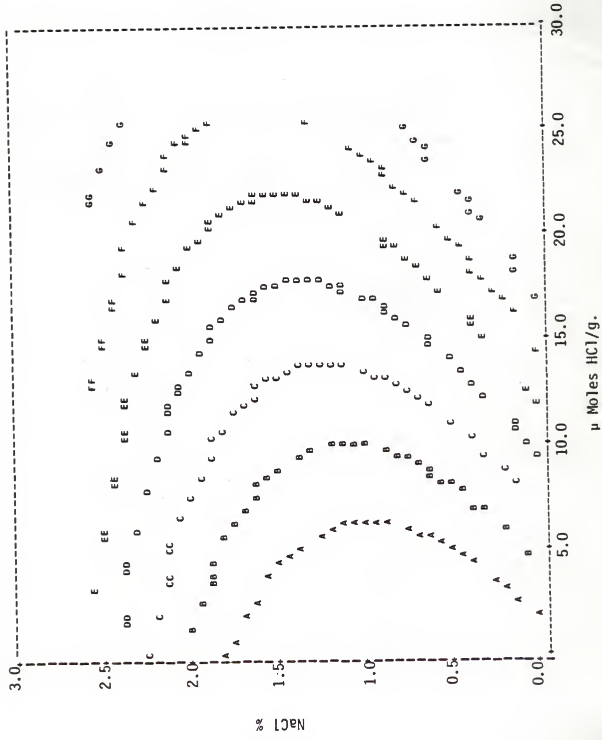

NaCl %
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5.0
10.0
15.0
20.0
25.0
30.0
µ Moles HCl/g.

Figure 3A. Contour plot of the specific loaf volume at varying levels of HCl and NaCl without oxidant in the formula (A = 4, B = 4.5, C = 5, D = 5.5, E = 6, F = 6.5)

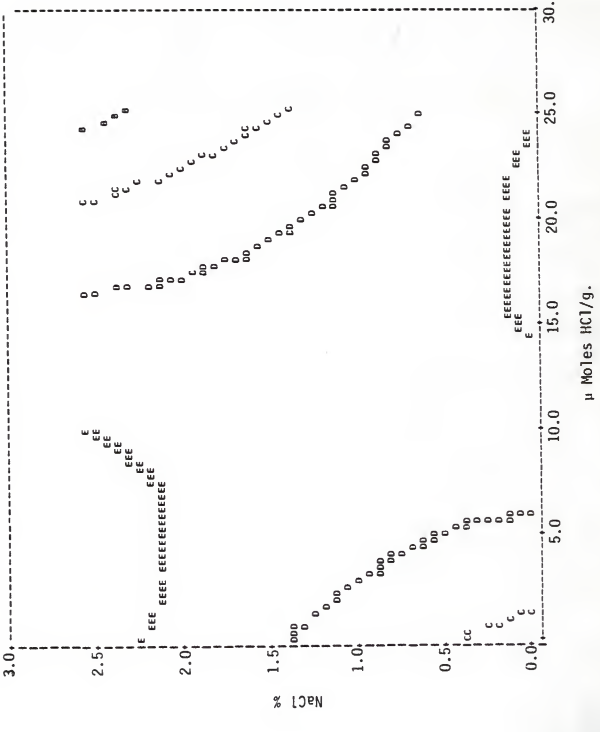
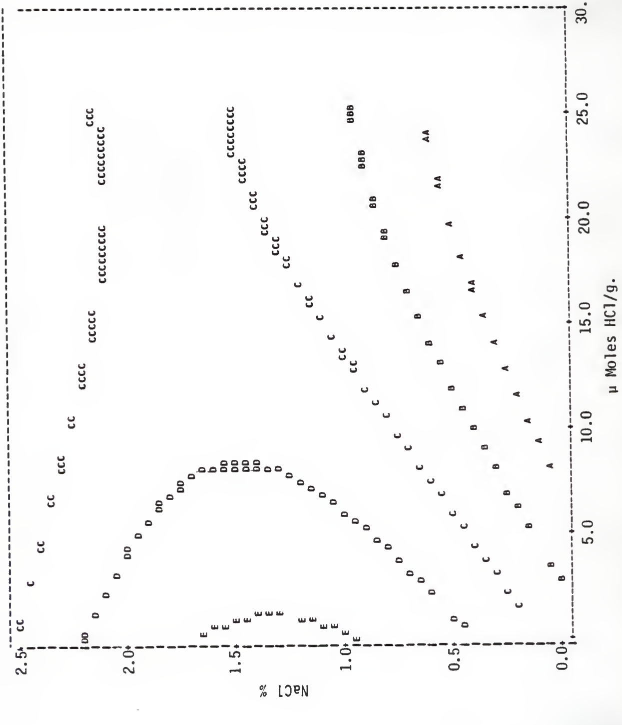

NaCl %
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5.0
10.0
15.0
20.0
25.0
30.0
µ Moles HCl/g.

Figure 4A. Contour plot of the specific loaf volume at varying levels of HCl and NaCl with oxidant in the formula (A = 3, B = 4, C = 5, D = 6, E = 7)


NaCl %
μ Moles HCl/g.
0.0
0.5
1.0
1.5
2.0
2.5
5.0
10.0
15.0
20.0
25.0
30.0

THE COMBINED EFFECTS OF SALT AND ACID

ON WHEAT FLOUR STRENGTH

by

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The combined effects of HCl and NaCl on wheat flour strength were studied by means of measuring the physical properties and baking quality of the dough. The combined effects were found to increase mixing time, stability, and slightly loaf volume. When the optimum level of potassium bromate was used in doughs treated by different combinations of salt plus acid a characteristic of over-oxidized doughs appeared and a decrease in loaf volume obtained. If salt plus acid are present in a dough, then no oxidant would be required and this was due to the marked strengthening effect that was produced by these two reagents. The combined effect of salt plus acid on the balance between resistance to extension and extensibility of the dough was very important in determining loaf volume and crumb characteristics. Cysteine chloride was used to improve the extensibility of doughs treated by salt plus acid. The improvement in the extensibility maintained the balance between the resistance to extension and the extensibility of the dough, thus the strengthening effects of salt plus acid were more pronounced as measured by loaf volume potential. The amount of cysteine required to improve the extensibility of the dough was quite constant regardless of the stiffness or the strength of the dough. The degree at which the extensibility was improved depends on dough stiffness or strength. The cysteine level which improved the extensibility was only slightly higher than the level which effectively reduced mixing time. The degree that mixing time was decreased depends on the amount of cysteine added rather than the strength or the stiffness of the dough.

A combination of 10 μ mole HCl, 40 ppm cysteine and 2% salt gave better loaf volume and grain than the control. Thus both cysteine and a combination of HCl and NaCl should be called dough improvers.