STUDIES ON THE PRODUCTION OF U.S. WHITE PAN BREAD USING MECHANICAL DOUGH DEVELOPMENT

by

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INTRODUCTION

The commercial development of continuous breadmaking processes has brought about many changes in breadmaking technology. Continuous breadmaking was rapidly accepted by the baking industry due to its efficiency and important economic advantages. Approximately 20 to 30 percent of commercial white pan bread in the United States is produced by this process (55). However, this process has met with some resistance largely because of the relatively different bread characteristics that it produces. Some consumers feel that the bread made by the continuous process differs in such attributes as bread structure and flavor compared to those of conventional bread, and as a result considerable complaints have been received from consumers (54). The major complaints are: tender and doughy bread crumb that disintergrates with wet fillings, execessive shrinkage when toasted, and a lack of fermentation flavor and aroma (22). Therefore, the initial rapid success of continuous breadmaking process has leveled off over the last several years.

To overcome this problem, extensive investigations have been conducted on improving the quality of bread made by the continuous process to achieve bread characteristics resembling those of conventional bread. Examples of these efforts include: introducing a brew system or preferment into this process, and conventional processing of continuous mix dough after extrusion. These changes brought about some improvements in bread quality, but not enough to overcome all objections. Therefore, the trend in the Unite States now appears to be away from continuous breadmaking towards conventional bread processes.

On the other hand, the Chorleywood bread process in England has been widely accepted by both consumers and industry and as a result now accounts for more than 70 percent of the total bread production in England (13, 18). This process achieves considerable savings in time and efficiency compared to the traditional bulk fermentation system previously used by the British.

Although successful in England, little work has been done to utilize this process for making U.S. white pan bread. British bread differs considerably in formulation and physical attributes compared to that produced in the U.S. Therefore, this study was undertaken with the hope that it would shed light on developing a process suitable for bread production in the U.S. with some economic advantages compared to conventional breadmaking.

The objectives of this study were:

1. To identify the optimum processing parameters required to produce U.S. sponge dough-type bread by a mechanical dough development procedure.

2. To study the effects of commercial surfactants (dough strengtheners and crumb softeners) on bread made by a mechanical dough development type method.

REVIEW OF LITERATURE

History of Mechanical Dough Development

Bread has been a major part of the human diet since the beginning of civilization, and most bread has been made with some types of fermentation. Many believe that significant modifications in dough structure during fermentation are, in part, responsible for dough development which represents a state of mellowness and yields sufficient extensibility for gas retention as well as the capability for production of the best quality bread. Therefore, the best bread has always been associated with and produced by fermentation.

A better understanding of the science and technology of breadmaking made it possible for people to think about making bread more economically, i.e. in a shorter time without sacrificing bread quality. Great efforts have been expended to achieve this goal. Fermentation was the major target to be attacked because it was the longest part of the breadmaking process. Some success has been realized in this area, but it has only recently been possible to bring about dough development by rapid mechanical action rather than by fermentation.

The first attempt at mechanical dough development was made by Swanson and Working (51) at the Kansas State Agricultural College. In this report, they showed that small doughs mixed at 60 or 120 r.p.m., which are much more rapid than conventional mixing speeds, and panned immediately without fermentation, could produce bread equal or better in every aspect than bread made by conventional mixing with fermentation. These results were striking and opened up new possibilities in breadmaking technology. However, their data was largely overlooked, and interest was not reborn until 1937.

At that time Baker (4) recognized the effects of mixing, oxygen and chemical oxidants on dough and suggested that mixing was responsible for dough development through the rearrangement of molecules to facillitate reaction with oxidizing agents. A special balance between mechanical action and oxidizing agents was strongly suspected, and different types of mixing were also emphasized to give stretching action in the dough rather than tearing, rubbing or cutting (3).

Continuous mixing process. On the basis of his previous work, Baker (5) developed the Do-Maker process which was the first process to achieve the goal of continuous dough development. In this process, small quantities of dough were mixed quickly and continuously so that it could supply the necessary output of dough for normal commercial operation. A certain amount of fermentation is considered necessary to impart acceptable bread flavor and taste. Approximately 20 to 30 percent of the commercial bread in the United States is produced by this process (55). Many researchers (5, 14, 31) reported that fermentation in conventional breadmaking could be replaced by using a liquid broth or preferment system containing sugars, malt, yeast and yeast food. The fermented broth could be incorporated into a dough with other dough ingredients in a pre-mixer and then prepared in the dough developer under intensive mixing under pressure. Snyder (49) summarized the advantages of this process over conventional processes as follows: 1) elimination of equipment 2) space saving 3) reduction in labor requirements and 4) savings in materials and ingredients.

On the other hand, continuous breadmaking still has some limitations. Many reports (24, 44) have outlined the problems encountered with the continuous mixing process. These problems related to bread quality and to the use of many of the ingredients, especially flour and milk (6, 46).

The typical grain of continuously mixed bread is small, spherical and characterized by regular sized cells due to the release of the pressure developed in the mixing chamber. The cell structure is totally disoriented due to ommission of the moulding stage (44). All these factors bring about a tender, weak, and doughy crumb structure, which was quite different from the crumb characteristics the consumers were used to. This also accounted for the alleged lack of flavor in bread made by this method (44).

In an attempt to refine the process to alter the bread characteristics to resemble those of conventional bread, the brew procedure and the ingredients of the preferment system were thoroughly investigated by many researchers (7, 47). This work brought about some improvement in the quality of continuous mixed bread. However, it was not enough to satisfy consumers and their preference is still largely for the bread made by conventional processes.

Chorleywood process. Attempts to apply modern breadmaking technology to commercial breadmaking were very active in England where a different type of bread compared to that of the U.S. was produced. English bread is characterized by a lean formula and very dense structure, with a specific volume around 3.8 (41).

The continuous breadmaking process, developed in United States, received a great deal of attention from British scientists and considerable success was achieved in making a British type bread by this process. British bakers still face the same problems as U.S. bakers when using this process (54). However, intensive study on batch type mechanical dough development at Chorleywood resulted in the production of an acceptable U.K. type bread. The most important characteristic of the Chorleywood process was that the critical factor for optimum dough development was the total amount of work imparted to the dough, which was centered around 0.4 horse power per pound per minute for a very wide range of flours (2, 54). Other characteristics of this process included increased level of oxidant (ascorbic acid), extra water addition, increased yeast level, fat addition and mixing under partial vacuum to reduce air cells in the dough. The time required to impart optimum work input was also a special feature of this process; less than five minutes was recommended as optimum. Bread produced by the Chorleywood process now acounts for over 70 percent of the total bread production in England (13, 41).

Major Characteristics of Mechanical Dough Development

Work input. The high level of work input in conjunction with high level of oxidizing agents is the most important factor in the production of good quality bread by mechanical dough development (23), and the main factor contributing to the reduction in fermentation time of conventional bread processes (52, 54). In addition, mechanical work is applied to the dough very intensively within a short time. A certain level of mixing speed is also a prerequisite to attain optimum dough development (39).

Critical minimum mixing speed varied depending on the mixer type, but the work input was not altered when different mixing speeds were employed (34). The success of this process involved the selection of an appropriate mixer; hexagonal mixing plates were used to give sufficient mixing action in a short period of time (54).

Oxidant level. A high level of a particular oxidizing agent or combination of oxidizing agents is reported to be necessary for mechanical dough development (2, 9, 18, 50). The exact mechanism of this action is not clearly understood yet, but a likely explanation can be suggested involving the combination of high oxidant levels with the high level of intensive mixing action, and summarized as follows:

The intensive mixing action by a specially designed mixer provides the unique mixing action of stretching and opening up of the gluten protein to expose the masked sulfhydryl group present in the glutenin to chemical attack of oxidizing agents. A similar phenomenon is thought to occur during the bulk fermentation period in the conventional breadmaking process.

This eventually increases the number of sulfhydryl groups which can interact with other strained disulfide bonds produced by violent mixing action. Consequently, this brings reactive sites into contact at a very rapid rate which markedly increased the interchange reaction, that will yield the correct spatial configuration for optimum dough development (54).

Generally recommended levels and combinations of oxidizing agents are 75 ppm of ascorbic acid, a combination of 10 to 20 ppm of potassium iodate and 40 to 50 ppm of potassium bromate, and a combination of equal amount of ascorbic acid and bromate (13, 50).

Water absorption, yeast level and dough temperature. Compared to the water absorption in the conventional breadmaking process, 2 to 3 percent of extra water absorption is required for optimum dough machinability and final bread quality. This is due mainly to the decreased loss of fermentable solid material as a result of the lack of bulk fermentation and will lead to an increase in bread yield (18, 19).

Increased level of yeast is another feature of this process. The elimination of bulk fermentation necessitates a higher rate of gas production in the first hour or so of reduced processing time. This can be brought about by using high levels of yeast and a high dough temperature. A 50 to 100 percent increase in yeast level is recommended (2, 9).

A markedly high dough temperature is typical in this process, because of the comparatively large amounts of work input. The dough temperature is controlled by many factors, but mainly by the work input level. Approximately, 5 °F. increase in dough temperature was observed for each watt-hour per pound of dough (32, 54). The optimum dough temperature of Chorleywood bread process lies between 84 °F. and 88 °F. (2, 54).

Current Research for Making U.S. White Pan Bread by Mechanical Dough Development

The striking success of the Chorleywood process in England has been very impressive to other parts of the world, especially in the United States. Efforts to utilize this process for making U.S. type white pan bread were undertaken and a few researchers (2, 16, 33) and commercial bakers (19) tried to make acceptable U.S. type white pan bread by this process. The possibility for this effort was solidly estabilished by their efforts, but many problems remain to be solved before this process can be feasible for commercial bread-making. Esters (19) reported that the 417 r.p.m. of high speed mixing was able to produce acceptable U.S. type bread without fermentation and also reported the optimum conditions for the baking process and modified formula for this process.

Kilborn and Tipples (33) reported a study on mechanical dough development for U.S. type bread that would be comparable to sponge and dough bread. They modified the bread formula for mechanical dough development with a minimum of change based on sponge and dough processes and concluded that the bread produced by mechanical dough development was as good as the bread made by conventional sponge dough process in quality. They also conducted panel tests to detect the flavor difference but reported no difference in flavor. As far as bread flavor is concerned, many arguments are still unresolved especially on the role of fermentation in flavor development. Some workers (34, 45) reported that fermentation might have little or no effect on bread flavor while others found that fermentation was a prerequisite to produce acceptable bread flavor (11). A very interesting report (44) has been published on bread flavor claiming that the bread flavor is attributable more to a difference in crumb texture than to any lack of actual flavor components.

Others (2, 9, 16) also reported the possibility that the batch type mechanical dough development was as beneficial for U.S. type breadmaking as for U.K. type breadmaking. However, only a very small portion of bakeries are using this process in the United States and also their major product by this method is hearth type bread rather than white pan bread. The reason for this was postulated that the success in U.K. was due mainly to the relatively different dough system and a different degree of dough development desired compared to U.S. type breadmaking (33). Another reason for this was supposed to be the baker's preconception of fermentation and the lack of research done on this in terms of commercial feasibility to provide the full confidence on this process for U.S. white pan breadmaking.

MATERIALS AND METHODS

Materials

The flour used was milled by Ross Milling Co. from a blend of Hard Red Winter Wheat and Spring Weat. The flour was malted and enriched to meet the standards of identification for commercial white flour. Laboratory analysis showed this flour to contain 13.7 % moisture, 11.5 % protein and 0.44 % ash (data on a 14 % moisture basis). The Brabender Farinograph absorption was 60.6 % and peak time was 6.0 minutes. Other data on the flour include Agtron color of 61 and falling number of 275. For the study on the oxidizing agents system, four different oxidizing agents were used. Four different dough strengtheners were also used to study the effect of dough strengtheners on the bread made by this process. Cysteine (L-cysteine hydrochloride monohydrate) was used as a reducing agent to cut down the mixing requirement. Table 1 includes all information on the chemicals used in this experiment. Dough strengtheners were dissolved in 54 ^{o}F. water before use.

Methods

Baking procedure. A modified bread formula and baking procedure obtained from preliminary experiments based on the characteristics of mechanical dough development were chosen for this experiment. The formula is presented in Table 2.

The baking procedure used in this experiment is as follows: wet ingredients including water, yeast suspension and oxidant solution were added first and the rest of the dry ingredients were added simultaneously. Mixing started immediately after the applied vacuum attained a certain constant level. The ingredients were mixed under 17 mm Hg of vacuum for 30 seconds and then mixing

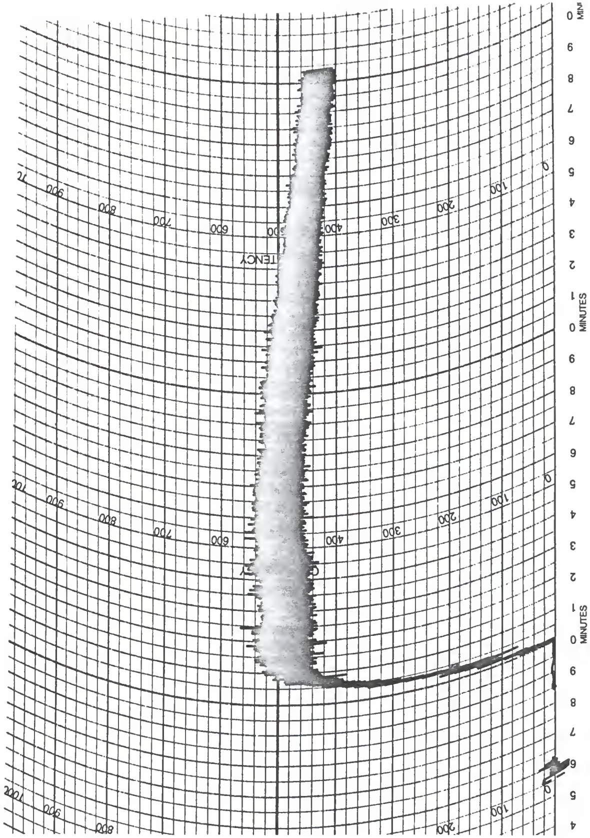


Plate 1. Farinogram of the flour used

Table 1. Chemicals Used in the Experiment

Chemicals	Brand	Function	Manufacturer
Potassium Bromate	-	Oxidizing Agent	Mallinckrodt, Inc. St. Louis, Missouri
Potassium Iodate	-	"	"
Ascorbic Acid	-	"	"
Azodicarbonamide (ADA)	-	"	Aldrich Chemical Company Milwaukee, Wis.
Mono-diglycerides + Polysorbate 60 (P-60/MG)	TANDEM 11H	Dough Strengthener and Crumb Softener	ICI United Inc., Wilmington, Delaware
Ethoxylated Mono-diglycerides + Mono-diglycerides (EMG/MG)	XPANDO	"	Breddo Food Products Corporation, Kansas City, KS.
Succinylated Mono-glycerides + Mono-glycerides (SMG/MG)	XMB - 6	"	Eastman Chemical Products Inc., Kingsport, Tenn.
Sodium Stearoyl 2-Lactylate (SSL)	EMPLEX	"	Patco Products, Kansas City, Mo.
Cysteine Hydrochloride Monohydrate		Reducing Agent	Sigma Chemical Company St. Louis, Mo.

Table 2. Original Formula

Ingredient	Percent(flour basis)	Grams	Recommended Formula for Sponge and Dough Process(% flour basis)
Flour	100	3000	100
Water	60	1800	57
Yeast	3.5	105	2.0
Salt	2.0	60	2.0
Sugar	5.0	150	6.0
Shortening	3.0	90	3.0
N.F.D.M.	2.0	60	2.0
$KBrO_3$	40 ppm	120 mg	-
KIO_3	10 ppm	30 mg	-
Arkady	-	-	0.25
		5275	

was stopped to clear the mixer wall. The rest of the mixing was done under the same level of vacuum as previously described. After mixing, the dough was dumped out and scaled immediately to 539 gm and the temperature was recorded. The scaled dough was then rounded and kept in an intermediate proofing cabinet at 86 °F. and 85 % relative humidity for 10 minutes. The dough was then punched, moulded, panned and proofed to 1.5 cm above the pan at 105 °F. and 93 % R.H. and then baked at 425 °F. for 25 minutes. After 45 minutes cooling the bread was bagged and sealed in a polyethene bag and stored at room temperature. Bread scoring was conducted the next day.

Bread evaluation. Bread volumes were measured immediately after baking by rape seed displacement and weights were measured for determination of specific volume.

Arbitrary standards for grading grain structure were prepared by 0.5 point intervals of grain score from 6.0 to 9.0. Actual grading on grain structure was done by comparing samples to the standards.

Crumb color was measured with the Agtron Multichromatic Abridged Reflectance Spectrophotometer Model M 300 with monochromic spectral line of the blue mode (436 nm of wavelength). The scale was standadized using standard disc # 44 and # 68 to read 0.0 and 100.0, respectively. Measurements carried out on half an inch thick slices cut from the middle of the loaf. Black paper with a 2 by 2 inch square hole was used to block the escaping light at the edges of the slice and to standardize the reflectance area between slices. Both sides of the slice were checked and readings were averaged.

Crumb firmness of the sliced bread was measured one day and four days after baking. Two slices, one inch thick, from the middle part of the bread were tested for firmness on the Bloom Gelometer.

Scorings on crust color, break and shread and symmetry were also conducted by visual judgement. But it was thought that too much subjectiveness and experimental error could be easily incorporated into these scorings. Therefore, these results were not used as input data for the Statistical Analysis System (SAS) but used only as a reference.

Mixing conditions. The Tweedy 35 High Speed Dough Mixer Developer was used in this study. This was the smallest mixer in the series of Tweedy's high speed mixers available for commercial use. It can handle dough quantities from 7 to 60 pounds; 11 pounds of dough per batch were used in this experiment.

The Tweedy mixer is especially designed to impart large amounts of work into the dough in short periods of time, usually in less than five minutes. It also has a unique control system capable of accurately measuring the amount of work input into the dough by setting the Energy Input Controller with watt-hrs per pound of work input or mixing time in seconds.

The amount of work required for a given mix depends upon the total weight of the dough. Therefore, to calculate the required amount of work input, the weight of the total ingredients in pounds or kilograms was determined and multiplied by the intended watt-hrs per pound or kilogram. The following calculation gives an example;

Total weight of ingredients = 11.6 lbs (5.25 Kgs)

For 7 watt-hrs/lb = 11.6 x 7 = 81.2

For 15.5 watt-hrs/Kg = 5.25 x 15.5 = 81.2

Therefore, watt counter was set at 81.

Another operational feature includes two different tilt positions such as full tilt and half tilt for operational convenience.

Experimental design. Four seperate experiments were designed and conducted.

The first experiment was on the effects of processing conditions on mechanically developed bread quality. The conditions studied were water absorption, work input and dough temperature. The objective of this experiment was to find the best combination of these three conditions which produces the best quality bread and to detect the possible interaction between them.

The technique of Response Surface Methodology (RSM) described by Cochran and Cox (15) was used. This technique involves taking certain data points from a factorial design and solving for a response surface containing the desired response of dependable variables such as specific volume or grain structure, as a function of the independent variables of water absorption, work input and dough temperature.

Each of the three variables was investigated at five different levels; Table 3 shows the variables and their levels. The factorial design of three variables with five different levels each is presented in Table 5. Dependent variables were used as input data (Y) and the regression coefficients were computed by the Taylor expansion equation:

$$Y = B_o + B_1X_1 + B_2X_2 + B_3X_3 + B_{11}X_1^2 + B_{22}X_2^2$$
$$+ B_{33}X_3^2 + B_{12}X_1X_2 + B_{13}X_1X_3 + B_{23}X_2X_3.$$

The computer program generates the coefficients of regression equation.

In order to find the combination of levels of the three variables where the maximum or minimum occurs, we took the partial derivatives of the quadratic model with respect to each of the variables and set them equal to zero. The point at which the maximum or minimum occurs is obtaintd by solving these equations simultaneously. In some cases, this procedure gave a solution which was outside the region covered by the experiment or a solution which can neither be a maximum or a minimum. In this case, the maximum was found by using a search procedure.

Table 3. Processing Conditions and Their Levels for RSM Study

Processing Conditions	Symbol	Code				
		-1.682	-1	0	1	1.682
Water Absorption (%)	X_1	56.6	58	60	62	63.4
Work Input (watt hrs/lb)	X_2	5.3	6	7	8	8.7
Dough Temperature (^oF)	X_3	85.3	88	92	96	98.7

Table 4. Oxidizing Agents and Their Levels for RSM Study

Oxidizing Agent	Symbol	Code				
		-1.682	-1	0	1	1.682
Ascorbic Acid (ppm)	X_1	0	15	37.5	60	75
Azodicarbonamide(ADA) (ppm)	X_2	0	8	20	32	40
Bromate (ppm)	X_3	0	10	25	40	50

Table 5. RSM Design for Three Variables at Five Levels

Number	Variable		
	X_1*	X_2*	X_3*
1	-1	-1	-1
2	1	-1	-1
3	-1	1	-1
4	1	1	-1
5	-1	-1	1
6	1	-1	1
7	-1	1	1
8	1	1	1
9	-1.682	0	0
10	1.682	0	0
11	0	-1.682	0
12	0	1.682	0
13	0	0	-1.682
14	0	0	1.682
15	0	0	0
16	0	0	0
17	0	0	0
18	0	0	0
19	0	0	0
20	0	0	0

* Refer to Table 3 and 4.

In a second experiment, the main effects studied were those of the oxidixing agents on bread characteristics. The same technique as described previously was used for this experiment. The oxidizing agents studied were ascorbic acid, bromate and azodicarbonamide; Table 4 shows the variables and their levels. The experimental design is the same as Table 5.

In a third experiment, the main effects studied were those of surfactants, or dough strengtheners, on bread qualities especially on crumb firmness. Four different dough conditioners were used at four different levels: 0.0, 0.17, 0.34 and 0.5 percent each. The dough conditioners studied are presented in Table [illegible].

Duncan Multiple Range Test, described by Snedeor and Cochran (48) was used to determine the significance of the difference between various treatments. This test was also programmed by computer using the S.A.S..

In the fourth experiment, the main effects studied were those of cysteine and work input on bread characteristics. The purpose of this experiment was to test the possibility of cutting down the work input level to a reasonable range. A large amount of work input which is required for optimum dough development with the high speed intensive mixer sometimes increases dough temperature beyond an acceptable level and causes serious damage to bread quality.

The same R.S.M. technique was used for this experiment, but with two independant variables and five different levels each. The design was slightly simplified compared to the other experiments. Taylor equation for this experiment was:

$$Y = B_0 + B_1X_1 + B_2X_2 + B_{11}X_1^2 + B_{22}X_2^2 + B_{12}X_1X_2.$$

Table 12 and Table 13 shows the variables with their levels and factorial design for this experiment.

RESULTS AND DISCUSSION

Preliminary experiment were conducted to determine optimum starting bread formula and procedures for the main experiment. The original bread formula (Table 2) and baking procedure were obtained from this preliminary experiment and used in the first experiment.

Effects of Work Input, Water Absorption and Dough Temperature

Work input, water absorption and dough temperature are the most important processing parameters in mechanical dough development. They may also interact or there may be a specific combination of these parameters to produce the best bread quality. Numerous researchers have noted that the work input varies depending upon the dough conditions (34); that the dough development is regulated by work input (39); and that low dough temperature increases the water absorption (50).

Response surface methodology was used to study these factors. This technique reduced the experimental work required to examine the effect of several processing conditions on a given response. The response surface equation and corresponding contour plots permit the investigator to quickly locate the optimum solution to a problem and verify the predicted solution experimentally.

The factorial design (15) used in this experiment gives the reasonable combination of 20 data points which are 2^3 factorial points, extra points with $\alpha = 1.682$, and 6 points at the center; i.e., zero point with 7 watt-hrs./lb. of work input, 60 % water absorption and 92 °F. dough temperature.

The data points, discussed above, were completely randomized to set the experimental order, and 20 batches were baked with two replications. In each batch, three loaves of breads were baked, and all the data were averaged. Appendix 1 contains all the experimental data for this experiment. The averaged scores on specific volume and grain structure, and overall score were used as input data for a computer program.

Specific volume. The response surface for specific volume (obtained from Appendix 1) was found to be:

$$\begin{aligned}\text{Specific Volume} = {} & 6.60704 + 0.19433\,X_1 + 0.28321\,X_2 + 0.25182\,X_3 \\ & - 0.01267\,X_1^2 - 0.05774\,X_2^2 - 0.036536\,X_3^2 \\ & - 0.1125\,X_1X_2 + 0.11125\,X_1X_3 - 0.09375\,X_2X_3\end{aligned}$$

where: X_1 = water absorption

X_2 = work input

X_3 = dough temperature.

This equation was used to locate the combination of three conditions that gave maximum scores of specific volume by differentiating with respect to each factor as previously described. However, it is necessary to determine if the estimated point is the true maximum point. For the estimated point obtained to give a maximum point, the matrix of the second partial derivatives must be negative definite. This is equivalent to $B_4 > 0$, $B_5 > 0$, $B_6 > 0$, $4B_4B_5 - B_7^2 < 0$, $|Q|^* > 0$. In this checking procedure, the response surface equation for specific volume did not satisfy the above conditions. Therefore, the maximum point of specific volume in the region covered by the experiment was found by a search procedure which checked every point inside the region

* Determinant of the matrix of the second partial derivatives.

Fig. 1. Contour plot of specific volume (C = 5.5, D = 6.0, E = 6.5, F = 7.0, G = 7.5) for work input and dough temperature at 62% water absorption.

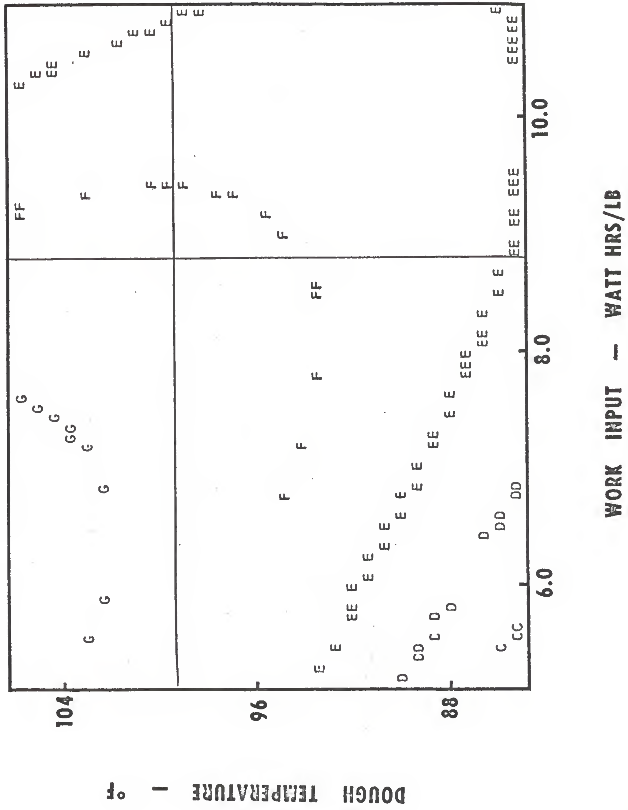

DOUGH TEMPERATURE — °F
104
96
88
6.0
8.0
10.0
WORK INPUT — WATT HRS/LB

Fig. 2. Contour plot of specific volume (B = 5.0, C = 5.5, D = 6.0, E = 6.5, F = 7.0) for work input and dough temperature at 58 % water absorption.

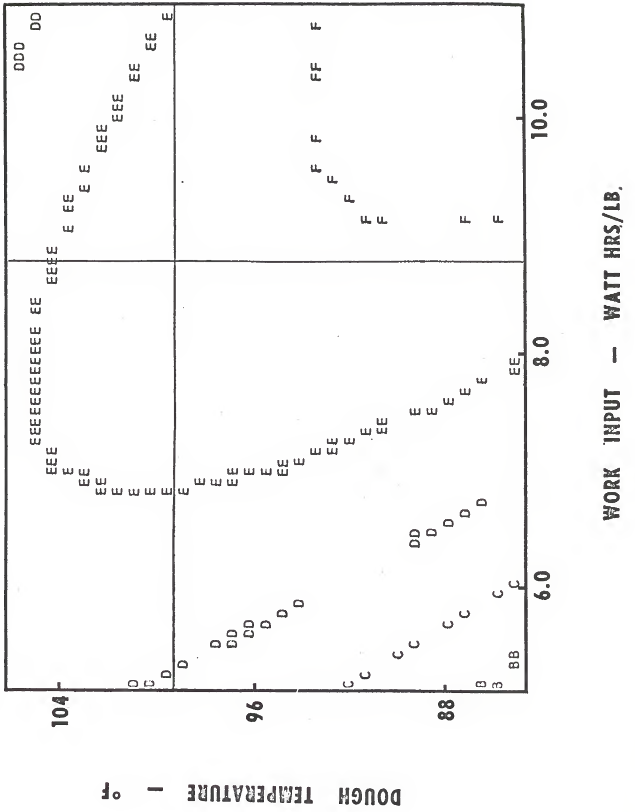
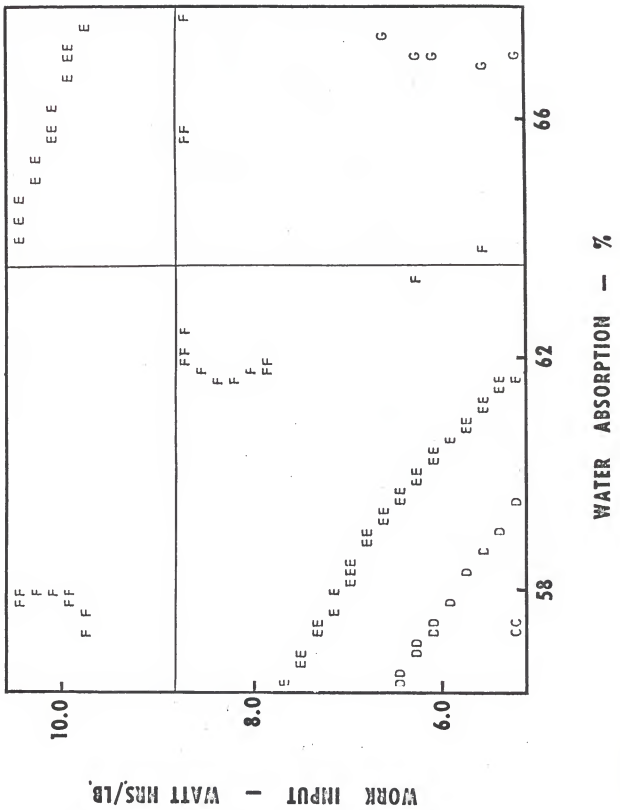

WORK INPUT — WATT HRS/LB.
6.0
8.0
10.0
DOUGH TEMPERATURE — °F
104
96
88

Fig. 3. Contour plot of specific volume (C = 5.5, D = 6.0, E = 6.5, F = 7.0, G = 7.5) for water absorption and work input at 61 °F. dough temperature.


WORK INPUT — WATT HRS/LB.
10.0
8.0
6.0
58
62
66
WATER ABSORPTION — %

at a certain interval to find the point of relatively high response. The interval of 0.5 in the RSM scale was used in this procedure.

In the region covered by the search procedure, 63 % water absorption, 7 watt-hrs./lb. of work input and 98 ^{o}F. dough temperature gave the largest specific volume.

Besides the search procedure, it is advisable to run several contour plots to understand what happens in the neighborhood of the maximum when the levels of variables are changed from their estimated optimum value.

A series of contour lines of two variables can be drawn holding other variables constant (27, 28). The third quadrant in all of the figures (1 through 18) is the region covered by the experiment.

Figure 1 shows the changes in specific volume as a function of work input and dough temperature at 62 % water absorption level. Higher dough temperature gave a higher specific volumes, but higher work input did not necessarily give a higher specific volume. In the region covered by the experiment, 7 watt-hrs./lb. of work input at 98 ^{o}F. dough temperature gave the largest specific volume. The extrapolated contour lines clearly show the relationship between work input and dough temperature.

Figure 2, like Figure 1, shows changes in specific volume as a function of work input and dough temperature. This time, however, the water absorption was reduced to 58 percent. The highest specific volume was obtained from the combination of high work input level (8.5 watt-hrs./lb.) and medium dough temperature (92 ^{o}F.), which is contrary to Figure 1. All the variables (water absorption, work input and dough temperature) interacted so that changing any variable affected the remaining two variables (Figure 3).

Grain score. The response surface obtained for grain was as follows:

$$\text{Grain} = 8.22488 + 0.031951\, X_1 + 0.34579\, X_2 - 0.19336\, X_3 - 0.14944\, X_1^2$$
$$- 0.14944\, X_2^2 - 0.20246\, X_3^2 + 0.01250\, X_1X_2 + 0.0875\, X_1X_3$$
$$- 0.15\, X_2X_3$$

where: X_1 = water absorption

X_2 = work input

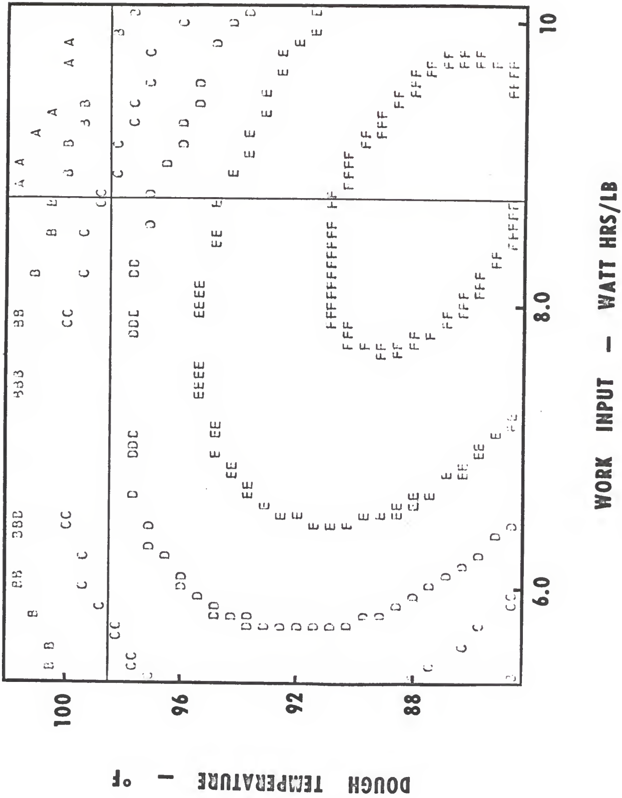
X_3 = dough temperature.

To determine if this equation gave a true maximum, a series of checking procedures were used as described earlier. The checking procedure showed that this equation satisfied the conditions for a true maximum point. Therefore, the equation was used to find the optimum combination of the three conditions that gave the maximum score for grain characteristics. The differentiation procedure previously described was used for this purpose.

The optimum combination of the three conditions for maximum grain score was found to be $X_1 = -0.1581$, $X_2 = 1.728$ and $X_3 = -1.1520$, which corresponded to about 60 % water absorption, 8.7 watt-hrs./lb. of work input and 87.5 ^{o}F. dough temperature. These levels lie in the region covered by the experiment, with the exception that the work input level is marginal for the upper limit of the region investigated. In this case, an experiment was conducted to verify that the maximum point was the true maximum, because the quadratic equation could give misleading results when applied outside the region of data collection. The experiment did verify the maximum point.

Several contour plots were drawn to determine how the grain score changed when the variable levels were changed from their optimum. Figure 4 shows the response of grain scores as a function of work input and dough temperature at 60 % water absorption. The estimated maximum point is clearly visible

Fig. 4. Contour plot of grain score (A = 6.0, B = 6.5, C = 7.0, D = 7.5, E = 8.0, F = 8.5) for work input and dough temperature at 60 % water absorption.


DOUGH TEMPERATURE — °F
100
96
92
88
6.0
8.0
10
WORK INPUT — WATT HRS/LB

on the oval shape contour lines. A slow decrease in grain score was observed as the levels of work input and dough temperature are changed from their optimum conditions, but beyond about 7.0 watt-hrs./lb. of work input and 94 ^{o}F. dough temperature, the decrease in grain score was accelerated as expected.

Figure 5 and 6 illustrate the effects of water absorption and dough temperature, and water absorption and work input on grain score at constant levels of work input and dough temperature, respectively. From Figure 4, 5 and 6, several conclusions can be drawn. First, since the contour lines of Figure 4 are oval shaped with the long axis positioned from top left to bottom right, this may suggest an interaction between dough temperature and work input. This interaction may indicate that some movement away from the optimum variable levels could be made without significant decrease in grain score.

Secondly, the contour lines of Figure 5 are also oval shaped but project in the opposite direction compared to those in Figure 4. The interaction between water absorption and dough temperature may also provide more tolerence in grain score as the optimum variable levels move toward higher water absorption and higher dough temperature.

On the other hand, the contour lines in Figure 6 form almost round rather than oval patterns; this suggests that no interaction exists between water absorption and work input.

The statistical analysis of the data showed a significant interaction between work input and dough temperature and a significant interaction between water absorption and dough temperature. But no significant interaction was found between water absorption and work input ($\alpha = 0.05$).

Fig. 5. Contour plot of grain score (A = 6.0, B = 6.5, C = 7.0, D = 7.5, E = 8.0, F = 8.5) for water absorption and dough temperature at 8.5 watt-hrs/lb of work input.

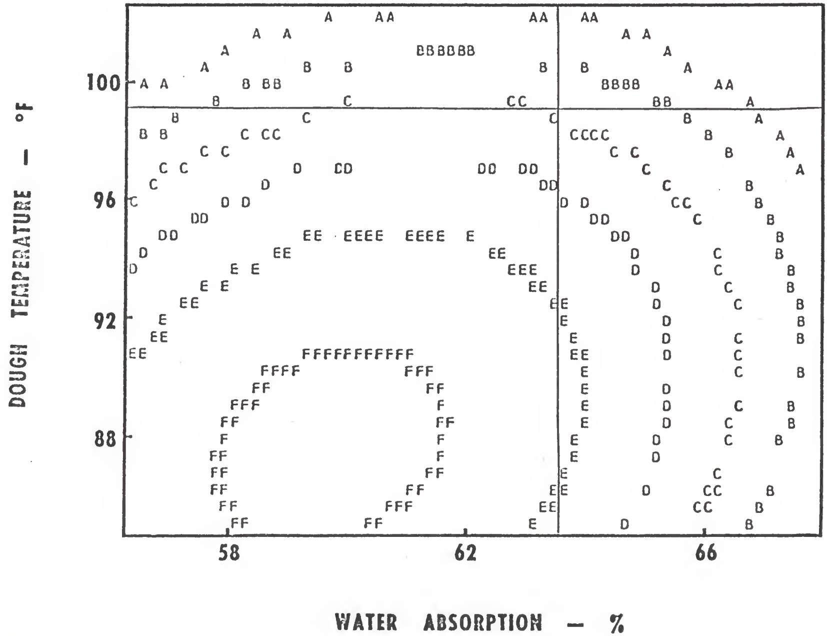

100
96
92
88
DOUGH TEMPERATURE — °F
58
62
66
WATER ABSORPTION — %

Fig. 6. Contour plot of grain score (A = 6.0, B = 6.5, C = 7.0, D = 7.5, E = 8.0, F = 8.5) for water absorption and work input at 88 ^{o}F. dough temperature.

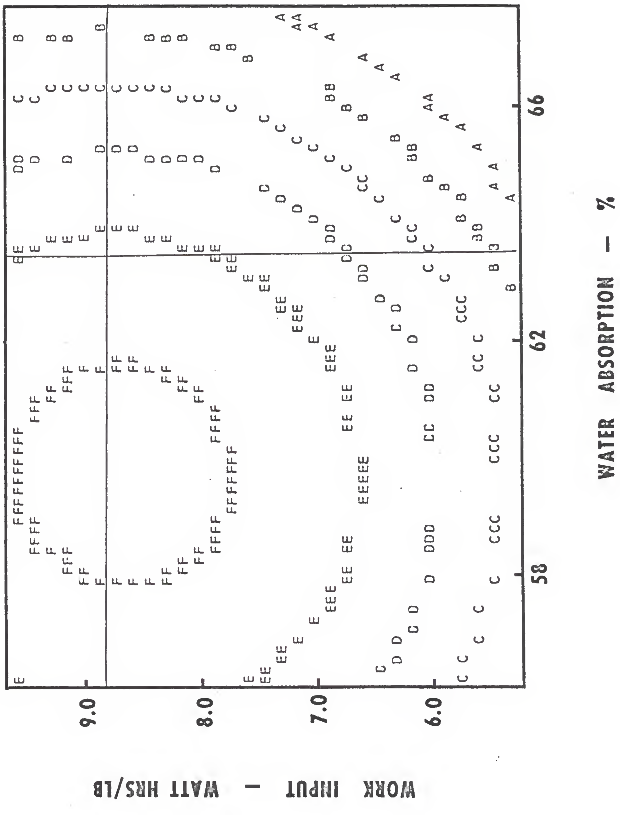

WORK INPUT — WATT HRS/LB
9.0
8.0
7.0
6.0
WATER ABSORPTION — %
58
62
66

Figure 4, 5 and 6 show that acceptable bread (i.e. bread with a grain score of 8.5) can be made within the following ranges of the three breadmaking parameters; 58 to 61.5 % water absorption, 7.7 to 9.8 watt-hrs./lb. of work input and 85 to 91 ^{o}F. dough temperature.

Overall bread characteristics. To determine the best combination of the three variables for the overall bread characteristics, we assigned equivalent numerical values for specific volume and grain score and used the combined overall score as input data for the quadratic model (see Table 6). For example, a specific volume of 6.8 and a grain score of 9.0 were considered as satisfactory and assigned 20 points each. The remainders of the scores were assigned according to the above standards.

The response surface obtained for the overall score was as follows:

$$\text{Overall Total} = 29.7136 + 1.81553\, X_1 + 6.1904\, X_2 + 0.1631\, X_3 - 1.7053\, X_1^2 - 2.1471\, X_2^2 - 2.5006\, X_3^2 - 0.9375\, X_1X_2 + 1.4375\, X_1X_3 - 2.3125\, X_2X_3$$

where: X_1 = water absorption

X_2 = work input

X_3 = dough temperature.

The checking procedures and the partial differentiation method were used to determine if this equation could give a true maximum and to calculate the estimated optimum point that would give the maximum overall score.

The estimated maximum point was found to be $X_1 = -0.5333$, $X_2 = 2.1607$, $X_3 = -1.1198$, which corresponded to 59 % water absorption, 9.2 watt-hrs./lb.

Table 6. Weighed Overall Score

Specific Volume		Grain Score	Arbitrary Score
Processing Condition	Others		
6.8	7.0	9.0	20
6.6	6.8	8.8	18
6.4	6.6	8.6	16
6.2	6.4	8.4	14
6.0	6.2	8.2	12
5.8	6.0	8.0	10
5.6	5.8	7.8	8
5.4	5.6	7.6	6
5.2	5.4	7.4	4
5.0	5.2	7.2	2
4.8	5.0	7.0	0

of work input, and 88 ^{o}F. dough temperature, respectively. This calculated maximum point correlated well with the contour plots drawn at different levels of each variable.

Figure 7 illustrate the effect of work input and dough temperature on the overall score at 59 % water absorption. The oval-shaped contour lines show an interaction between work input and dough temperature. Again, more tolerance to overall score reduction was expected when work input was decreased and dough temperature was increased from the optimum levels for the variables.

Figure 8 shows the effect of water absorption and dough temperature on the overall score. An interaction between water absorption and dough temperature was observed in Figure 8 and changes in the direction of higher water absorption and higher dough temperature were expected to be desirable for more tolerance to overall score reductions.

It is, however, very difficult to satisfy all three conditions at the maximum point, largely because of the high work input required with low dough temperature. Dough temperature increase is almost linearly proportional to the work input imparted to the dough. Therefore, low dough temperature with high work input is difficult to achieve under laboratory conditions.

Considering the effects of the three variables on the overall score, we decided to change the levels of the three variables from the maximum to the direction of higher water absorption, lower work input and higher dough temperature. Even though all three characteristics of specific volume, grain score and overall score are considered together, the above changes were thought to be reasonable.

Fig. 7. Contour plot of overall score (A = 10, B = 15, C = 20, D = 25, E = 30, F = 35) for work input and dough temperature at 59 % water absorption.

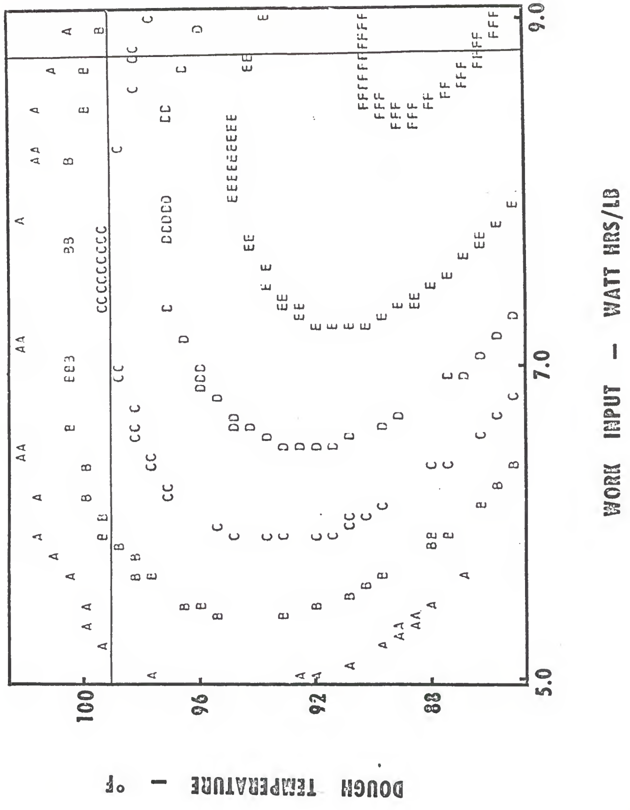
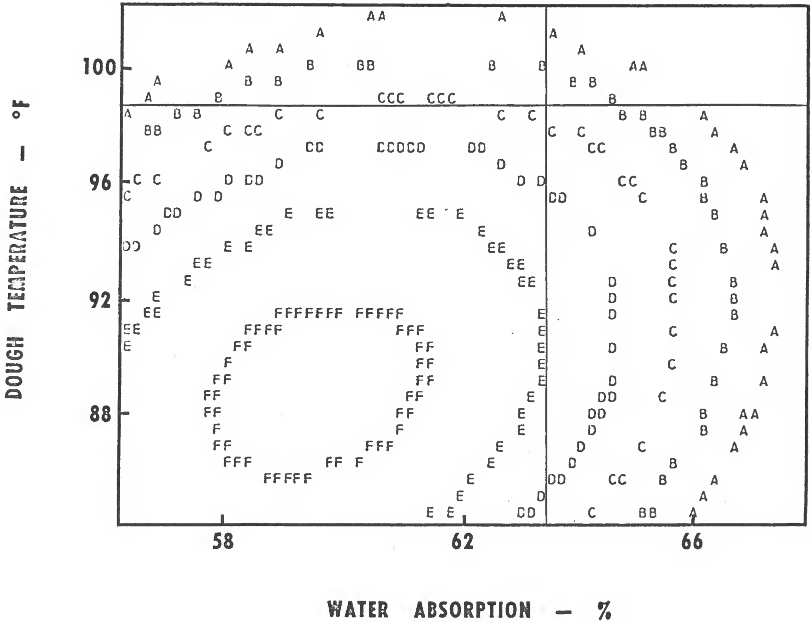

WORK INPUT — WATT HRS/LB
5.0
7.0
9.0
DOUGH TEMPERATURE — °F
88
92
96
100

Fig. 8. Contour plot of overall score (A = 10, B = 15, C = 20, D = 25, E = 30, F = 35) for water absorption and dough temperature at 8.5 watt-hrs/lb of work input.


DOUGH TEMPERATURE — °F
100
96
92
88
58
62
66
WATER ABSORPTION — %

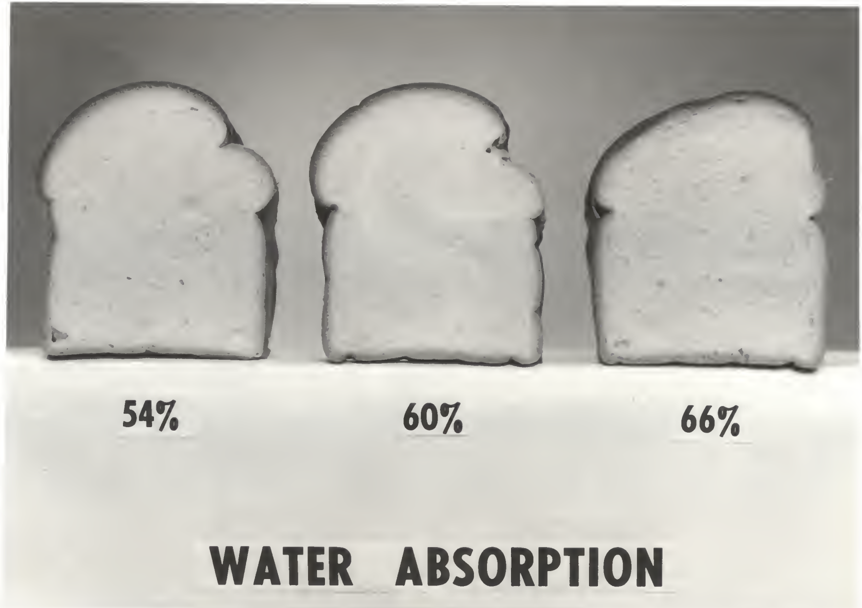


Plate 2. Effect of Water Absorption

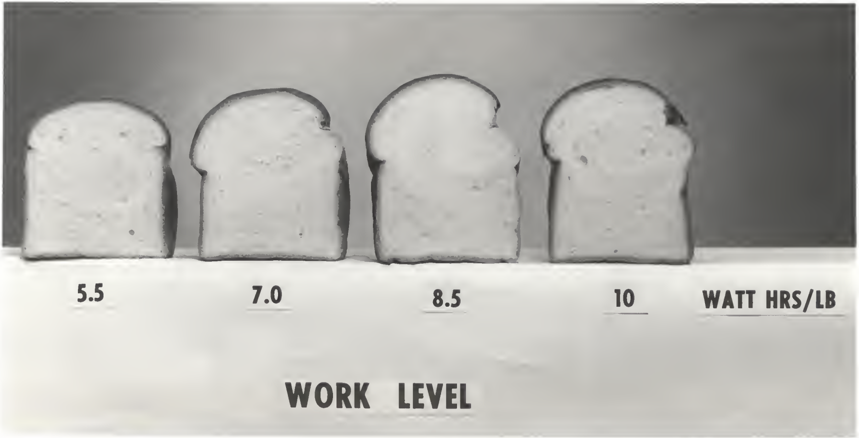


Plate 3. Effect of Work Input

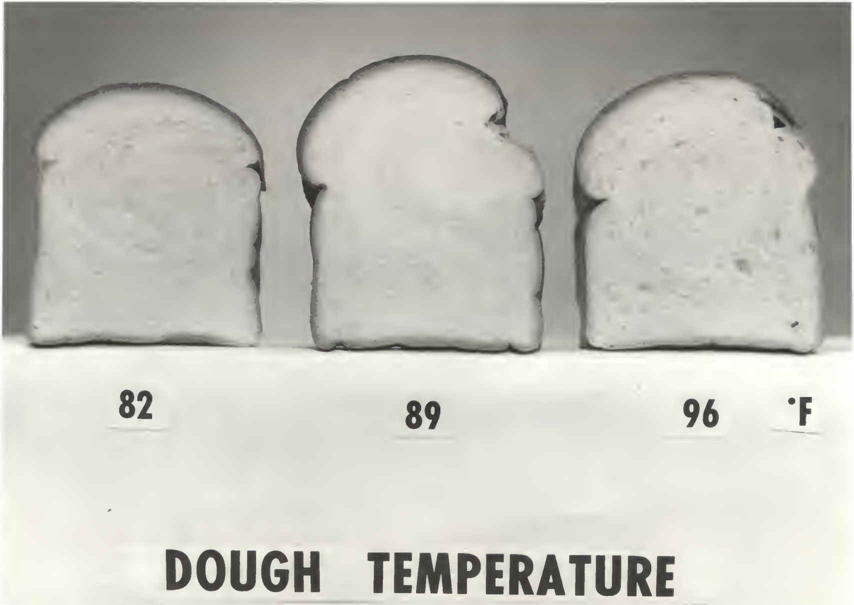


Plate 4. Effect of Dough Temperature

In summary, with respect to the U.S. type breadmaking by batch type mechanical dough development, the RSM study showed:

1. Water absorption, work input and dough temperature were equally important in the production of desirable bread characteristics, as shown in Plate 2, 3, and 4.

2. Interactions between these three variables were highly suspected and it was supported by the shapes of contour lines and statistical analysis on the data. However, more study on these interactions is strongly recommended.

3. The optimum level of each variable for producing good bread quality was: 58 to 61 % water absorption, 8.0 to 10.0 watt-hrs./lb. of work input and 85 to 91 ^{o}F. dough temperature. This was based on the overall score.

4. Based on the estimated maximum point and the interactions between three variables, the optimum variable levels were considered to be 60 % water absorption, 8.5 watt-hrs./lb. of work input and 89 ^{o}F. dough temperature. This combination was used for the rest of the experiment.

<u>Oxidizing Agents</u>

A high level of oxidant has been recommended by several researchers for mechanical dough development (9, 18, 50, 54). The combination of intensive mechanical work and the chemical reaction resulting from high levels of oxidizing agents has reportedly been a key to successful mechanical dough development (12, 54).

Many reports have been published on the oxidizing system commonly used in mechanical dough development (23, 50). However, the oxidation requirements vary depending upon the flour (42), formula, and processing. Consequently, the optimum oxidizing system for U.S. white pan breadmaking by mechanical dough development varies considerably with that used for conventional breadmaking processes or for the Chorleywood bread process (19, 33). Therefore, a study was undertaken to determine the optimum oxidizing system for U.S. white pan breadmaking by batch type mechanical dough development.

Three commonly used oxidizing agents (potassium bromate, ascorbic acid and azodicarbonamide) were chosen for this study. Although protassium iodate is still utilized by industry, it was excluded from this study because many unfavorable iodate effects have been reported (1, 43).

The RSM technique also was used in this experiment. Preliminary experiments were conducted to determine a relevant range of levels for each oxidizing agent. Table 4 shows the levels of oxidizing agents used and their corresponding RSM scale. The experimental design used is shown in Table 5. Specific volume, grain score and overall score were used as input data for the computer program, the experimental data is presented in Appendix 2.

Specific volume. The response surface for specific volume was found to be:

$$\text{Specific Volume} = 6.7165 + 0.05183\,X_1 - 0.09498\,X_2 + 0.16676\,X_3 + 0.001463\,X_1^2 - 0.033\,X_2^2 - 0.2460\,X_3^2 + 0.07562\,X_1X_2 + 0.050622\,X_1X_3 - 0.20678\,X_2X_3$$

where: X_1 = ascorbic acid

X_2 = ADA

X_3 = bromate

This equation did not satisfy the conditions for producing the true maximum. Therefore, the maximum point was found by a search procedure, assisted by several contour plots drawn at different levels of variables in the region covered by the experiment. The 40 ppm of bromate without ascorbic acid and ADA showed the highest specific volume. Figure 9 and 10 illustrate the effect of bromate on specific volume. The specific volume was gradually increased by raising the bromate level up to 40 ppm. The specific volume was decreased above 40 ppm bromate. At low bromate levels desirable specific volumes (around 7.0) were not possible with any combination of ADA and ascorbic acid. From these results, it was concluded that bromate is the most important oxidizing agent for obtaining desirable specific volume.

The effect of ADA on specific volume was unfavorable. The maximum specific volume obtained using up to 40 ppm ADA was approximately 6.0. ADA also reacted unfavorably in combination with other oxidizing agents. Increased levels of ADA decreased specific volume markedly. For example, a specific volume of 7.0 at 40 ppm of bromate was decreased to 6.6 by adding 20 ppm of ADA. However, at low bromate levels (less than 25 ppm), the addition of ADA improved the specific volume slightly, as shown in Figure 9.

The effect of ascorbic acid on specific volume was quite different from that of ADA. Figure 10 illustrates the effect of ascorbic acid and bromate on specific volume at zero level of ADA. As a single oxidizing agent, ascorbic acid was not effective up to 120 ppm. At low bromate levels, the addition of ascorbic acid decreased specific volume slightly. However, when the bromate level was maintained at 40 ppm, the addition of ascorbic acid slightly increased the specific volume. The relationship of ascorbic acid to specific volume at various bromate levels may be explained by the reaction mechanism of ascorbic acid in the dough. Ascorbic acid must be converted to its dehydro form either by enzyme or oxidizing agent to exert an oxidizing effect on the dough. At low bromate levels the oxidizing capability of the

Fig. 9. Contour plot of specific volume (A = 4.0, B = 5.0, C = 5.5, D = 6.0, E = 6.5, F = 7.5) for ADA and bromate at 60 ppm ascorbic acid.

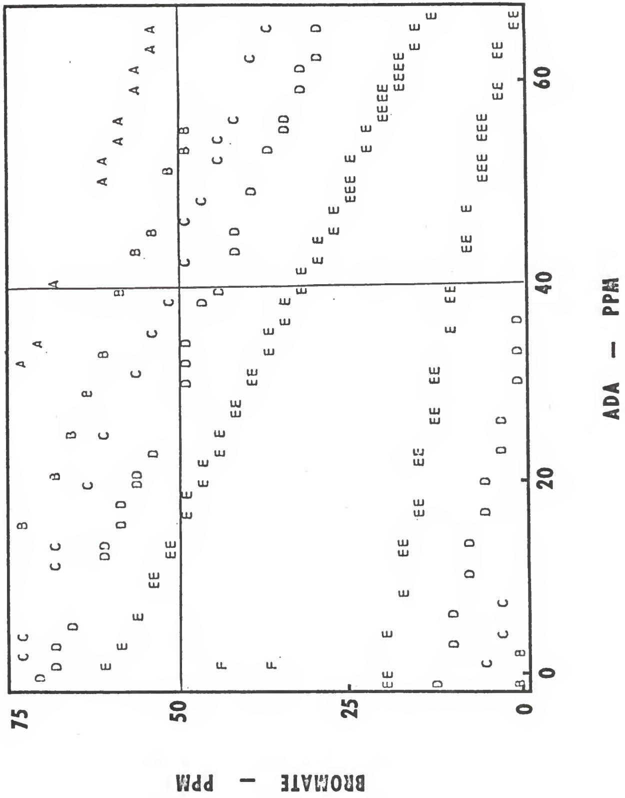

BROMATE — PPM
75
50
25
0
ADA — PPM
0
20
40
60

Fig. 10. Contour plot of specific volume (B = 5.0, C = 5.5, D = 6.0, E = 6.5, F = 7.0) for ascorbic acid and bromate at 0 ppm ADA.

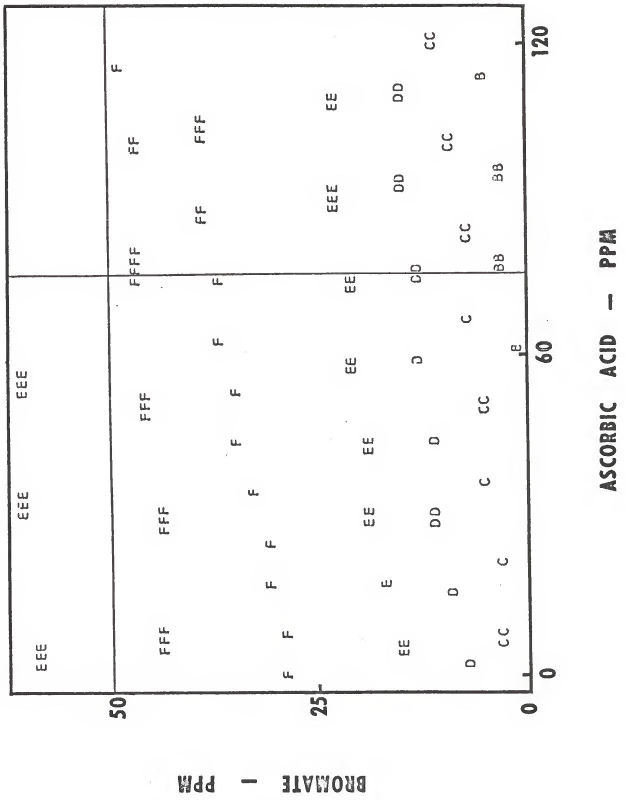
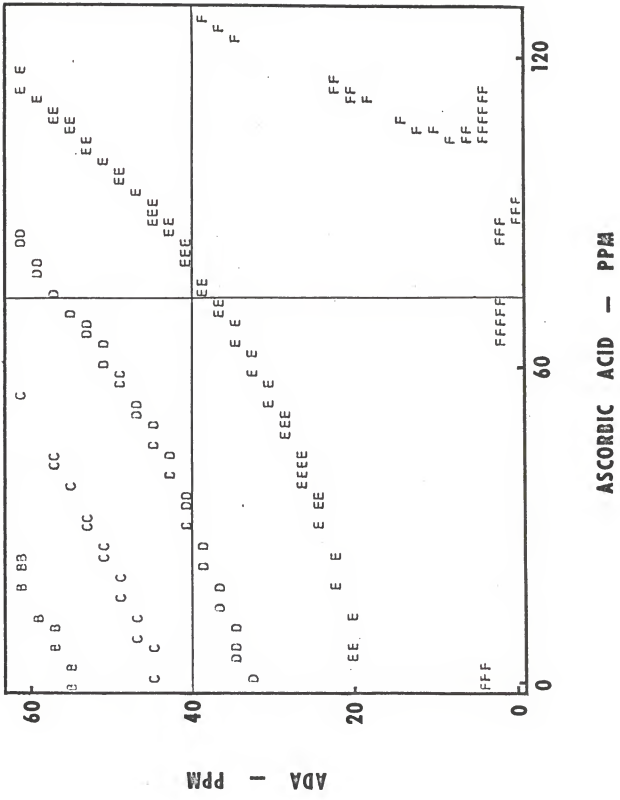

ASCORBIC ACID — PPM
0
60
120
BROMATE — PPM
0
25
50

Fig. 11. Contour plot of specific volume (B = 5.0, C = 5.5, D = 6.0, E = 6.5, F = 7.0) for ascorbic acid and ADA at 40 ppm bromate.


ADA — PPM
0
20
40
60
ASCORBIC ACID — PPM
0
60
120

dough system may be impaired because the dough system may lose some of its oxidizing power by converting ascorbic acid to dehydro ascorbic acid. However, at high levels of bromate, the oxidizing capability of the dough system is enough to convert ascorbic acid to its dehydro form without significantly reducing the oxidizing power of the dough. The combined effects of ascorbic acid and ADA are illustrated in Figure 11 drawn at 40 ppm of bromate. The unfavorable effect of ADA on specific volume could be partially overcome by the use of high levels of ascorbic acid.

Grain score. Grain characteristics of the bread were considered to be important because the effect of over-oxidation, normally associated with large specific volume, is readily pronounced in grain characteristics. Over-oxidation results in serious damage to bread quality. It is characterized by a very open grain structure and poor crumb texture. In addition, it is often associated with large holes along moulding lines and bottom corners of bread (Plate 4) despite the large specific volume.

The response surface for grain characteristics was found to be:

$$\text{Grain} = 8.1126 - 0.01854 X_1 - 0.32226 X_2 - 0.1410 X_3 + 0.07514 X_1^2 - 0.10159 X_2^2 - 0.33134 X_3^2 - 0.039375 X_1X_2 + 0.001875 X_1X_3 - 0.414375 X_2X_3$$

where: X_1 = ascorbic acid

X_2 = ADA

X_3 = bromate.

This equation did not satisfy the conditions for producing the true maximum. Therefore, a search procedure was used to locate the maximum point in the region covered by the experiment, and the contour plots, to study the effects of varying levels of oxidizing agents away from their estimated optimum levels.

The highest grain score was obtained with approximately 30 ppm of bromate without ADA. This grain score was not affected by adding up to 50 ppm ascorbic acid. This tendency was indicated by a series of contour plots drawn at different levels of oxidizing agents.

The effect of bromate and ascorbic acid without ADA on grain characteristics is illustrated in Figure 12. A change in grain score was observed depending upon the levels of ascorbic acid. The grain score remained almost constant up to 50 ppm ascorbic acid, but increased gradually above that level. The beneficial effect of ascorbic acid on grain characteristics was detectable only above 50 ppm. This is probably due to the fact that ascorbic acid was not an effective oxidizing agent for this process. Therefore, relatively high levels of ascorbic acid were required for its beneficial effect on grain characteristics.

Figure 13 shows the response of grain score as a function of ADA and bromate at the constant level of 60 ppm ascorbic acid. Without ADA, the grain score increased gradually up to 30 ppm of bromate and decreased again by additional bromate. The combined effect of bromate and ADA on grain score was almost the same as for specific volume. At the low levels of bromate, the use of ADA was slightly beneficial but above 15 ppm of bromate it became detrimental, as shown in Figure 13.

<u>Overall score</u>. Overall score was used to determine the effects of oxidizing agents on specific volume and grain structure simultaneously. As shown in Table 6, a specific volume of 7.0 and grain score of 9.0 was

Fig. 12. Contour plot of grain score (B = 6.5, C = 7.0, D = 7.5, E = 8.0, F = 8.5, G = 9.0) for ascorbic acid and bromate at 0 ppm ADA.

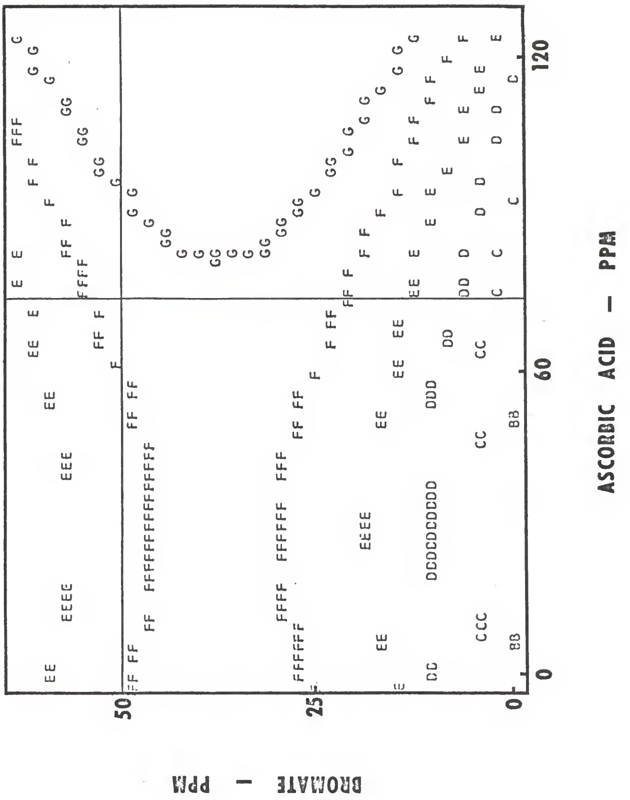
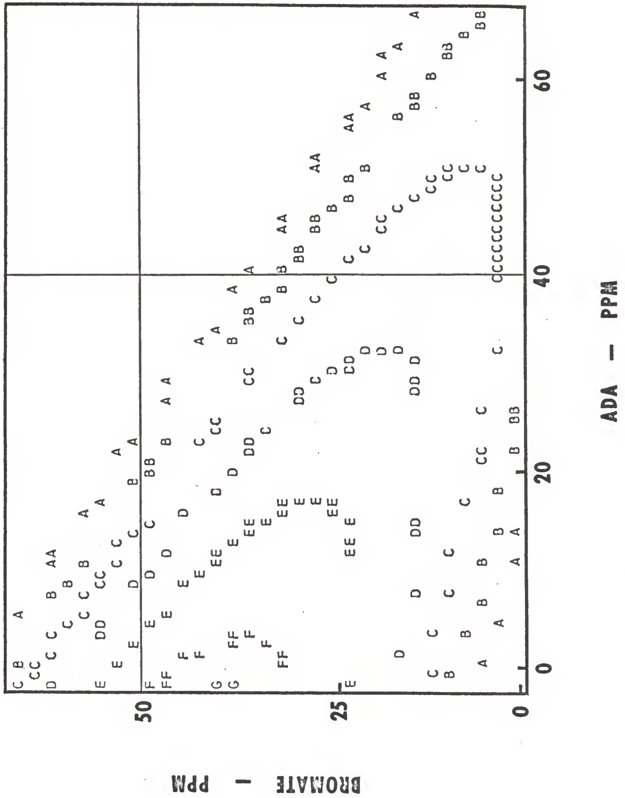

ASCORBIC ACID — PPM
0
60
120
BROMATE — PPM
0
25
50

Fig. 13. Contour plot of grain score (A = 6.0, B = 6.5, C = 7.0, D = 7.5, E = 8.0, F = 8.5) for ADA and bromate at 60 ppm ascorbic acid.


ADA — PPM
0
20
40
60
BROMATE — PPM
0
25
50

considered as satisfactory and received 20 points each. A specific volume above 7.0 was considered undesirable and did not receive additional points.

The response surface for overall score was found to be:

$$\text{Overall} = 27.9445 + 0.073215\ X_1 - 3.71592\ X_2 + 0.65894\ X_3 + 0.90746\ X_1^2 - 1.1250\ X_2^2 - 5.6317\ X_3^2 - 5.5\ X_2X_3$$

where: X_1 = ascorbic acid

X_2 = ADA

X_3 = bromate.

Because this equation did not satisfy the conditions for a true maximum point, a search procedure and contour plots were used to locate the optimum combination of these three oxidizing agents which gave the highest overall score in the region covered by the experiment.

The highest overall scores were observed at 40 ppm of bromate without ADA. However, the overall score at 40 ppm of bromate was increased linearly with higher levels of ascorbic acid. Figures 14 and 15 show overall score as a function of ADA and bromate, and ascorbic acid and bromate, respectively.

The importance of bromate as a part of an oxidizing system is also indicated in Figure 14 and 15. With low levels of bromate, it was impossible to produce an acceptable bread. In the region investigated in this experiment no acceptable overall score was found with any combination of ascorbic acid and ADA at low bromate levels. It was proven that the bromate level is quite critical in dough, and that the careful optimization of bromate is required to avoid over-oxidation and to utilize the beneficial effect of the bromate.

The effect of ascorbic acid and ADA on overall scores, either as single oxidizing agents or in combination with other oxidizing agents, were similar to those observed for grain score, as shown in Figures 14 and 15.

In summary, it was found that well balanced levels of bromate are required to obtain the most beneficial effect on bread quality as confirmed by other researchers (43, 54). The over-oxidizing effect of bromate became pronounced above 40 ppm.

The effect of ascorbic acid on bread characteristics was different than expected. Several possible reasons may be offered for this result. One might be the unique mechanism of ascorbic acid in which it is converted to dehydro ascorbic acid in order to exert its oxidizing effect in dough.

During the preliminary study conducted to determine the optimum region of each oxidant, a series of experiments were carried out to establish the effectiveness of ascorbic acid as a single oxidizing agent for this process. Poor results were obtained using up to 150 ppm ascorbic acid (Plate 5).

This was contradictory to the claim found with use of the Chorleywood bread process in England which recommended 75 ppm of ascorbic acid as a standard oxidizing system. But in the present experiment, ascorbic acid used alone performed so poorly that an acceptable loaf of bread could not be produced.

In mechanical dough development, a closed mixing system under vacuum was used because the vacuum was very beneficial to grain structure. A much smoother and finer cell structure was obtained under vacuum. Therefore, we suspected that the oxygen availability was not great enough to convert ascorbic acid to its dehydro form. In this case ascorbic acid might react as a reducing agent rather than an oxidizing agent as reported by Mauseth (40),

Fig. 14. Contour plot of overall score (A = 6.0, B = 6.5, C = 7.0, D = 7.5, E = 8.0, F = 8.5, G = 9.0) for ADA and bromate at 60 ppm ascorbic acid.

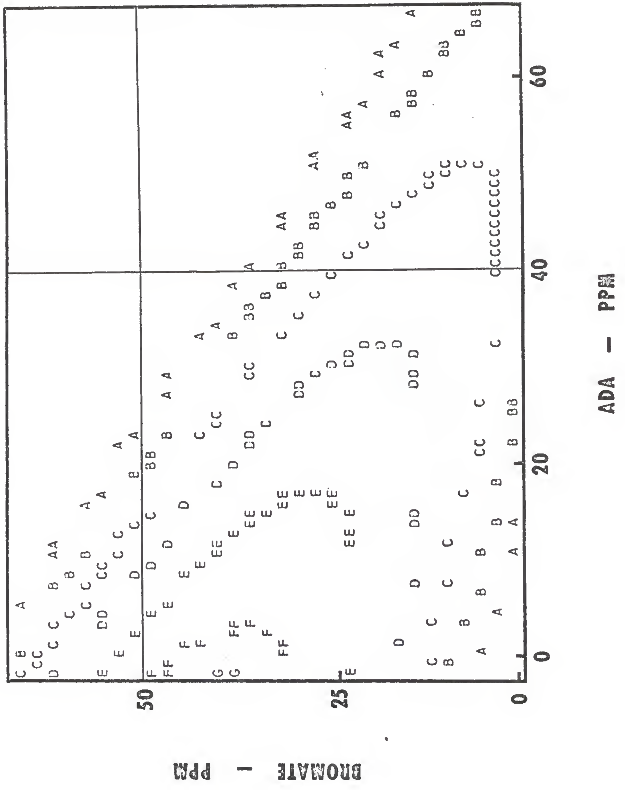
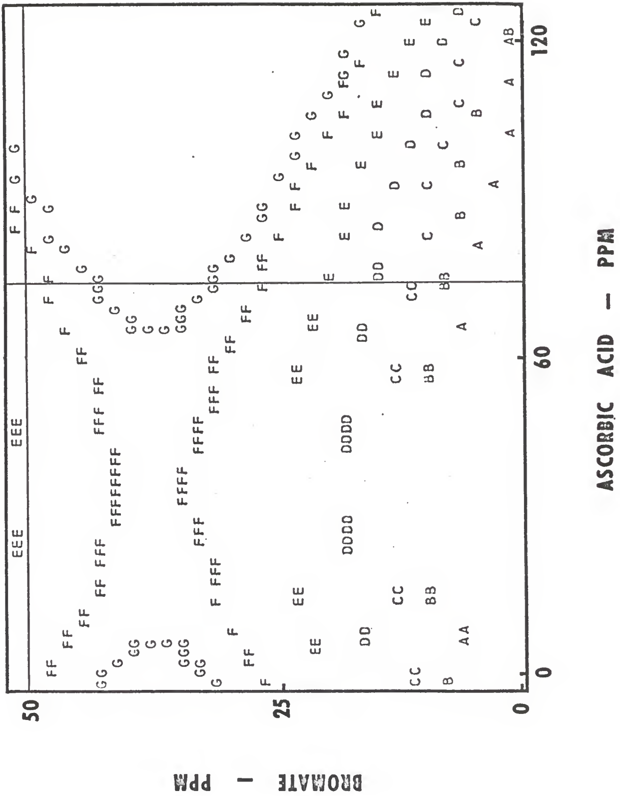

0
20
40
60
ADA — PPM
0
25
50
BROMATE — PPM

Fig. 15. Contour plot of overall score (A = 6.0, B = 6.5, C = 7.0, D = 7.5, E = 8.0, F = 8.5, G = 9.0) for ascorbic acid and bromate at 0 ppm ADA.


ASCORBIC ACID — PPM
0
60
120
BROMATE — PPM
0
25
50

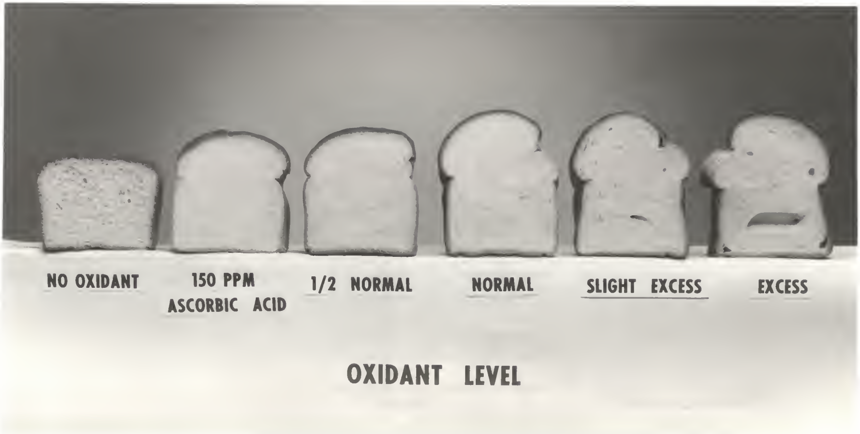


Plate 5. Effect of Oxidizing Agent

who concluded that the ascorbic acid reacted as a reducing agent in the so-called "oxigen starved" condition in the developer chamber of the continuous mixing system. Even in the Chorleywood bread process, the importance of air in the mixing system was noted (12). Therefore, lack of oxygen due to vacuum might cause the very poor performance of ascorbic acid when it was used as a single oxidizing agent.

Another series of experiments were conducted to determine if improving the oxygen availability to the dough during the mixing period would affect the bread quality. Several doughs with 150 ppm of ascorbic acid were mixed at atmospheric pressure in open and closed conditions. Few differences were observed between bread made from these doughs and bread made under vacuum. However, as shown in Plate 5, the bread made with 150 ppm of ascorbic acid was much better than the bread with no oxidizing agents at all, even though the bread was far from satisfactory. Therefore, one could suppose that the ascorbic acid exerted some oxidizing effect, although it was not as good as when used in combination with bromate.

We strongly suspect that the difference in bread formula and the degree of dough development in U.S. type white pan breadmaking as compared with the Chorleywood bread process may be mainly responsible for the unexpected results from ascorbic acid.

ADA was not a satisfactory oxidizing agent. Many reports (1, 43, 54) are available on the favorable effect of ADA as an oxidizing agent. The action of ADA was reported to be rapid and to extend over a long period, comparable to the action of iodate. The complimentary effect of ADA with bromate was reported in the ratio of 1:2 (ADA: bromate). However, those complimentary effects were observed in the present study only at bromate levels less than 25 ppm. A detrimental effect of ADA was observed at the optimum levels of bromate and ascorbic acid. In mechanical dough development, the fast acting oxidizing agent was supposed to be especially beneficial because of the high oxidizing agent requirement in a short period of intensive mixing. However, no benefit from ADA was observed in this experiment.

A possible explanation of this might be partly found in the rapid reaction rate of ADA, which may easily produce over-or under-oxidized doughs in a particular process. Williams (54) suggests that a sophisticated oxidant blend is required for sufficient tolerance in order for ADA to be used successfully. From this point of view, the RSM design may not be able to detect that particular situations which are very sensitive to the level of ADA.

To determine if the estimated optimum combination of oxidizing agents, (as indicated by search procedure and contour plots) gave the best quality bread, a series of experiments was conducted. This was,especially, necessary in order to check the pronounced beneficial effect of ascorbic acid outside the region covered by this experiment.

Two combinations of 30 and 40 ppm of bromate without ADA were used with increasing levels of ascorbic acid. The experiment showed that 40 ppm of bromate was on the verge of over-oxidation; therefore,30 ppm of bromate was considered as the safe bromate level combined with up to 80 ppm of ascorbic acid. Even with 30 ppm of bromate, more than 100 ppm of ascorbic acid produced the over-oxidizing effect in bread quality.

A few reports (8, 13, 50) also support the finding that the best oxidizing agent system results from a combination of bromate and ascorbic acid, even though their ratios were different.

In summary, in respect to the best oxidizing agent system for U.S. white pan breadmaking by mechanical dough development, the response surface study indicated:

1. Bromate was the most effective oxidizing agent system for this process.

2. Ascorbic acid as a single oxidizing agent was not effective in this process. The combined effect of ascorbic acid with other oxidizing agents depended upon the levels of other oxidizing agents and the level of ascorbic acid, itself. The beneficial effect of ascorbic acid was observed only at relatively high levels of oxidizing agents.

3. The effectiveness of ADA either in a single or combined oxidizing system was questionable for this process.

4. The recommended optimum combination of the three oxidizing agents studied for this process was 30 ppm of bromate with 80 ppm of ascorbic acid without ADA.

Dough Strengtheners

Dough strengtheners (surfactants) have become a common ingredient in breadmaking in the United States. Several reports (38, 44) have been compiled on the effectiveness of each of the dough strengthener on breadmaking.

Surfactants are known to produce a softer bread crumb and to thereby a beneficial effect on bread staling, which is one of the big problems faced by the baking industry (43). Other reported functions of surfactants in breadmaking include improving the crumb texture and softness, increasing volume, and sometimes reducing the required amount of shortening (43). Dough strengthening effects of some recently introduced surfactants are reported to include an improvement in the tolerance of dough to mechanical abuse during processing (30, 43).

Four commercially available dough conditioners, were investigated as to their effectiveness for U.S. type white pan breadmaking by batch type mechanical dough development.

The original bread formula and baking procedure revised with the results of the optimized three processing conditions and oxidizing agent system were used for this experiment. A simple experimental design was used to compare the effects of the four different dough strengtheners on several bread characteristics at four different levels which were evenly divided up to 0.5 % (flour basis), respectively. All 16 combinations were randomized and experimented in duplicate. The differences between the treatments were tested by Duncan's Multiple Range Test (48) using a Statistical Analysis System (SAS) computer package. Data from this experiment is found in Appendix 3.

Table 7 summarizes the effects of dough strengtheners on specific volume. Little difference in specific volume was observed between the treatments and

Table 7. Duncan's Multiple Range Test for Specific Volume

Treatment	Level	Replication	Grouping*		Mean
2	1	2		A	7.21
3	3	2	B	A	7.10
3	2	2	B	A	7.08
3	1	2	B	A	7.05
1	1	2	B	A	7.02
0	0	8	B		6.97
2	3	2	B		6.97
1	2	2	B		6.97
1	3	2	B	C	6.93
4	3	2	B	C	6.90
2	2	2	B	C	6.89
4	2	2		C	6.71
4	1	2		C	6.70

* Means with the same letter are not significantly different(alpha=0.05).

Treatment: 0 = control; 1 = polysorbate 60/MG; 2 = SSL; 3 = EMG/MG; 4 = SMG/MG

Level: 0 = 0 %; 1 = 0.17 %; 2 = 0.34 %; 3 = 0.50 %

the control. The differences observed by the Duncan Test included a significantly higher volume at 0.17 % SSL* and lower specific volumes at 0.34 % and 0.5 % of SMG*/MG compared to the control. However, the remaining levels of SSL and SMG/MG showed no significant difference in specific volume compared with the control. Results with the different levels of SSL were rather inconsistent. On the other hand, EMG/MG* showed a consistent improvement in specific volume, even though the differences were not significant, compared with control.

The above results agree with the reports of several researchers (38, 43, 44), with the exception of SMG. Therefore, it was concluded that there was little difference among the treatments and control in specific volume. The already optimized processing conditions and oxidizing agents system may have contributed to the lack of significant difference in specific volume between the control and dough strengthener treatments.

Table 8 summarized the effects of dough strengtheners on grain characteristics. In general, no significant differences in grain score were observed between the treatments and control with the exception of the poor grain score in 0.5 % of SMG/MG. This was supported by additional experiments. Therefore, it was suggested that the level of SMG/MG should not exceed 0.34 % for the best result of grain characteristics. A tendency to improve grain score when higher levels of dough strengtheners were used was observed, although the difference was not significant.

Significant improvements were observed in crumb color by the treatments of dough strengtheners as summarized in Table 9. Highly significant differences were observed in the high levels of dough strengtheners but no significant differences were observed in low levels of dough strengtheners compared

* Refer to Table 2.

Table 8. Duncan's Multiple Range Test for Grain Score

Treatment	Level	Replication	Grouping*		Mean
2	3	2		A	8.85
3	3	2		A	8.80
4	2	2		A	8.80
1	2	2		A	8.75
1	3	2		A	8.75
2	1	2		A	8.70
2	2	2		A	8.65
1	1	2		A	8.60
4	1	2		A	8.60
0	0	8		A	8.58
3	1	2	B	A	8.50
3	2	2	B	A	8.50
4	3	2	B		8.20

* Means with the same letter are not significantly different(=0.05).

Treatment:		Level:	
	0 = control		0 = 0.00 %
	1 = polysorbate 60 / MG		1 = 0.17 %
	2 = SSL		2 = 0.34 %
	3 = EMG / MG		3 = 0.50 %
	4 = SMG / MG		

Table 9. Duncan's Multiple Range Test for Crumb Color

Treatment	Level	Replication	Grouping*				Mean
3	3	2			A		72.5
1	3	2	B		A		70.0
4	2	2	B		A		69.5
2	3	2	B		A	C	68.0
1	2	2	B	D	A	C	67.5
3	2	2	B	D	A	C	66.5
4	3	2	B	D	A	C	66.0
2	1	2	B	D	A	C	64.5
4	1	2	B	D	E	C	63.5
3	1	2		D	E	C	60.5
1	1	2		D	E	C	60.0
2	2	2		D	E		59.5
0	0	8			E		57.4

* Means with the same letter are not significantly different(=0.05).

Treatment:		Level:	
	0 = control		0 = 0.00 %
	1 = polysorbate 60/MG		1 = 0.17 %
	2 = SSL		2 = 0.34 %
	3 = EMG/MG		3 = 0.50 %
	4 = SMG/MG		

to the control.

In general, color improvements were caused by the level rather than the kind of dough strengtheners. Thus, one would conclude that the higher level of dough strengtheners improved the crumb color significantly.

The improvement of crumb firmness is an interesting aspect of the use of dough strengtheners. A great deal of study has been conducted on this effect, but ambiguity still exists. However, the improving effect has been clearly observed in many studies (37, 43, 44).

In this experiment, the effect of dough strengtheners in improving crumb firmness was clearly observed. Significant differences were observed between treatments in crumb firmness of one day old bread (Table 10), but the differences leveled off in four day old bread (Table 11). Therefore, only two treatments, 0.5 % EMG/MG and 0.5 % SMG/MG, showed significant differences compared to that of control after four days.

In general, crumb firmness showed no correlation to the level of kind of dough strengtheners.

In summary, the effect of dough strengtheners on bread quality made by mechanical dough development was not so pronounced as it would be for bread made by conventional breadmaking processes, especially for specific volume and grain structure. However, crumb color and firmness showed significant improvement when compared to the control.

In general, no specific level or treatment significantly outperformed the control in all bread characteristics investigated in this experiment. The already optimized processing conditions and oxidizing agents system could be partly responsible for this, as well as the alleged softer crumb of bread made by mechanical dough development (2), although no attempt was

Table 10. Duncan's Multiple Range Test for Crumb Firmness after 1 Day

Treatment	Level	Replication	Grouping*				Mean
0	0	8			A		123.8
2	1	2	B		A		120.5
2	2	2	B		A		116.5
3	3	2	B	D	A	C	116.0
1	1	2	B	D		C	114.5
1	3	2	B	D		C	114.5
3	1	2	B	D		C	111.5
3	2	2		D	E	C	108.5
4	1	2		D	E	C	107.5
4	2	2		D	E	C	107.0
1	2	2		D	E		104.5
2	3	2			E		98.5
4	3	2			F		84.0

* Means with the same letter are not significantly different(=0.05).

Treatment: 0 = control
1 = polysorbate 60/MG
2 = SSL
3 = EMG/MG
4 = SMG/MG

Level: 0 = 0.00 %
1 = 0.17 %
2 = 0.34 %
3 = 0.50 %

Table 11. Duncan's Multiple Range Test for Crumb Firmness after 4 Days

Treatment	Level	Replication	Grouping*		Mean
0	0	8		A	210.3
1	1	2	B	A	204.5
4	1	2	B	A	203.5
2	2	2	B	A	195.5
3	2	2	B	A	193.5
2	3	2	B	A	191.0
2	1	2	B	A	189.0
3	1	2	B	A	188.5
4	2	2	B	A	187.5
1	3	2	B	A	181.5
1	2	2	B	A	180.0
3	3	2	B		173.0
4	3	2	B		169.0

* Means with the same letter are not significantly different(=0.05).

Treatment:	0 = control	Level:	0 = 0.00 %
	1 = polysorbate 60/MG		1 = 0.17 %
	2 = SSL		2 = 0.34 %
	3 = EMG/MG		3 = 0.50 %
	4 = SMG/MG		

made to prove this effect in this experiment.

Consistent improvements of all bread characteristics investigated could be observed at the 0.5 % level of EMG/MG, even though they were not always significant.

It was concluded from this that:

1. In general, little significant improvement in specific volume and grain score was observed from the use of dough strengtheners.

2. Significant improvements were observed in crumb color at the higher levels of dough strengtheners, and in crumb firmness at the 0.5 % level of EMG/MG and SMG/MG.

3. 0.5 % EMG/MG showed relatively good performance for all bread characteristics tested compared to the control, although the differences were not always significant.

Cysteine and Work Input

The study on the optimum combination of three processing conditions found work input and dough temperature located at the very margin of the region covered by the experiment. It presented considerable difficulty in controlling of dough temperature, because high work input normally results in a very high increase in dough temperature under normal processing conditions.

Since maintenance of optimum dough temperature is important to bread quality, a method of reducing work input and thereby reducing the extremely high dough temperature would be valuable. The reducing agent cysteine hydrochloride mono-hydrate, which is commonly used for chemical dough development (26), was studied to determine its potential in reducing work input without serious damage of bread quality. Similar attempts have been made for the Chorleywood bread process (54) and other mechanical dough development process and it was reported that the work input level could be cut considerably without impairing bread quality (35).

Many reports (10, 16, 25, 36) are available on the effects of cysteine on breadmaking processes and quality. Cysteine is one of the naturally occuring alpha amino acids, and through disulfide bonding, this can link protein subunits together into long chains. This cross link is mainly responsible for the structural stability and elasiticity of wheat gluten (54). Many studies (53, 54) have been conducted on the reaction mechanism of cysteine in dough systems. It can be postulated that if free cysteine is added to the dough system, it may rapidly react at the cross links to free the protein chains one from another, eventually leading to a rearrangement of protein chains into some optimum configuration, with even at relatively slow mixing speeds.

To study the combined effects of cysteine and work input on bread quality, a careful balance between work input and cysteine levels was required, since an imbalance of these two factors could result in either overmixing or undermixing of the dough. This point was also made by Mauseth (40).

The RSM technique was used for this purpose and a factorial design for two variables described by Cochran (15) was used with 13 data points. These points were randomized with duplicates samples. Table 12 includes the cysteine and work input levels covered by this experiment and their corresponding RSM scales and Table 13 shows the RSM design.

The original bread formula was revised by the findings obtained in the previous three experiments included optimized processing conditions, oxidizing agents, and the addition of 0.5 % EMG/MG. All of the data are in Appendix 4.

Specific volume. The following response surface was obtained for specific volume:

$$\text{Specific Volume} = 6.9767 + 0.12313\, X_1 - 0.13031\, X_2 - 0.09042\, X_1^2 - 0.13354\, X_2^2 - 0.09\, X_1X_2$$

where: X_1 = work input

X_2 = cysteine

It was apparent that this equation satisfied the conditions for true maximum, so the estimated maximum point was calculated by the method described earlier. The estimated maximum was $X_1 = 1.10$ and $X_2 = -\ 0.862$ which corresponded to 7.1 watt-hrs./lb. of work input and 15 ppm of cysteine, respectively. This maximum point was inside the region covered by the experiment.

A contour plot (Figure 16) was drawn for specific volume as a function

Table 12. Work Input and Cysteine and Their Levels for the RSM Study

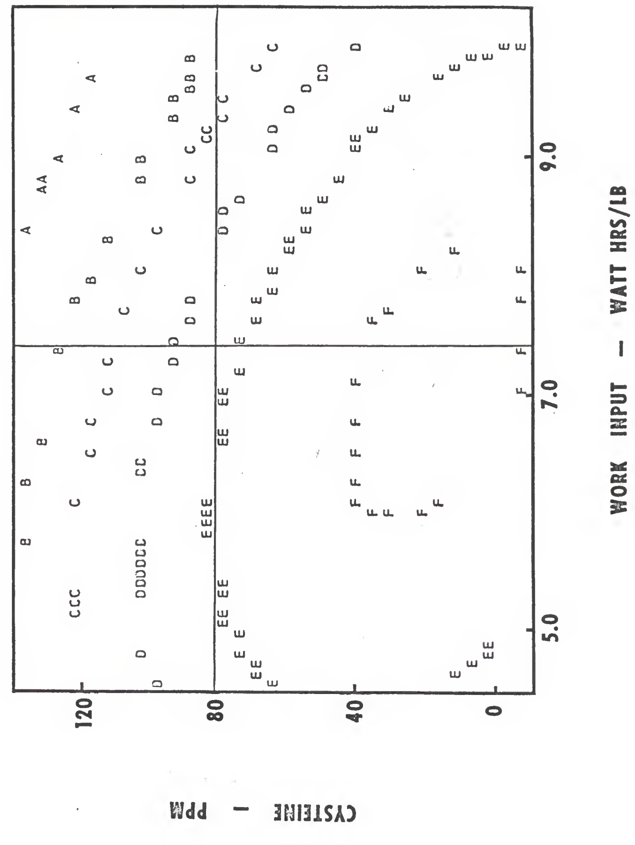
Independant Variable	Symbol	Code				
		-1.414	-1	0	1	1.414
Work Input (watt-hrs/lb)	X_1	4.6	5.0	6.0	7.0	7.4
Cysteine (ppm)	X_2	0	12	40	68	80

Table 13. RSM Design for Two Variables at Five Levels

Number	Variables	
	X_1*	X_2*
1	-1	-1
2	1	-1
3	-1	1
4	1	1
5	-1.414	0
6	1.414	0
7	0	-1.414
8	0	1.414
9	0	0
10	0	0
11	0	0
12	0	0
13	0	0

* Refer to Table 12.

Fig. 16. Contour plot of specific volume (A = 4.0, B = 5.0, C = 5.5, D = 6.0, E = 6.5, F = 7.0) for work input and cysteine.



WORK INPUT — WATT HRS/LB
CYSTEINE — PPM
5.0
7.0
9.0
0
40
80
120

of work input and cysteine. The estimated maximum point was well correlated with the contour lines which shape oval around the estimated maximum points.

Interaction was observed between the work input and the cysteine level as shown by the oval shape of the contour lines. This interaction may provide more tolerance in specific volume as variable levels move toward lower work input and higher cysteine levels.

Figure 16 shows that acceptable bread (i.e., bread with a specific volume of 7.5) can be made within the following ranges of the two breadmaking parameters: 6.0 watt-hrs./lb. of work input with 40 ppm of cysteine level.

Grain score. The response surface for grain score was found to be:

$$\text{Grain} = 8.50275 + 0.12794\, X_1 - 0.01206\, X_2 - 0.06001\, X_1^2 - 0.19437\, X_2^2 + 0.0625\, X_1X_2$$

where: X_1 = work input

X_2 = cysteine

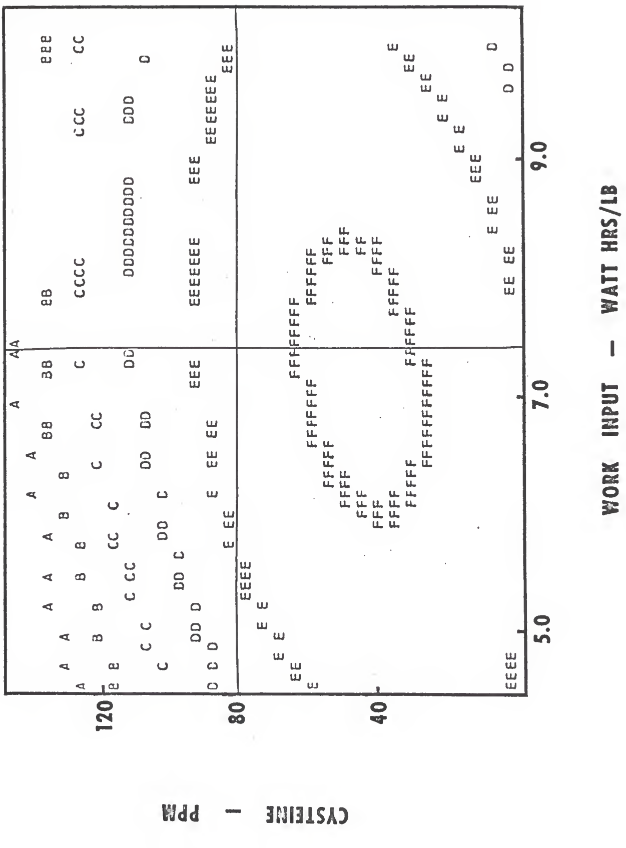
The estimated maximum point was $X_1 = 1.1459$ and $X_2 = 0.15322$ which corresponded to 7.15 watt-hrs./lb. of work input and 44 ppm of cysteine, respectively, which are all inside the region covered by the experiment.

Figure 17 shows the effect of varying cysteine and work input levels on grain characteristics. The over-and under-mixing effects were clearly observed when the levels were changed from their optimum. The minimum level of work input that can produce a grain score of 8.5 point was 6.0 watt-hrs./lb. of work input with 40 ppm of cysteine.

Overall score. The response surface for overall score was found to be:

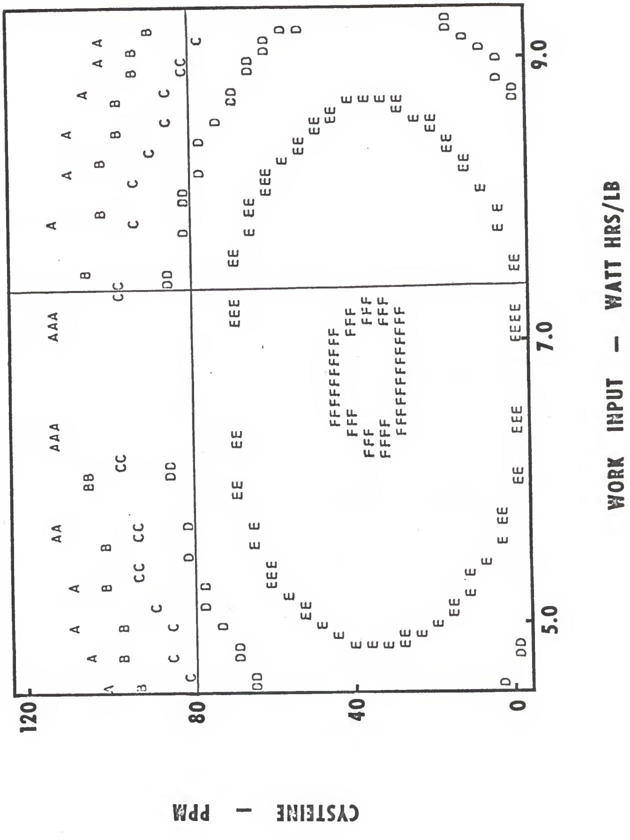
$$\text{Overall} = 34.36578 + 2.2207\, X_1 - 1.25018\, X_2 - 1.4474\, X_1^2 - 3.1787\, X_2^2$$

Fig. 17. Contour plot of grain score (A = 6.0, B = 6.5, C = 7.0, D = 7.5, E = 8.0, F = 8.5) for work input and cysteine.



CYSTEINE — PPM
120
80
40
WORK INPUT — WATT HRS/LB
5.0
7.0
9.0

Fig. 18. Contour plot of overall score (A = 10, B = 15, C = 20, D = 25, E = 30, F = 35) for work input and cysteine.


WORK INPUT — WATT HRS/LB
5.0
7.0
9.0
CYSTEINE — PPM
0
40
80
120

where: X_1 = work input

X_2 = cysteine

The estimated maximum point was $X_1 = 0.767$, $X_2 = - 0.19664$ which corresponded to 6.8 watt-hrs./lb. of work input and 32 ppm of cysteine, respectively.

Figure 18 shows the combined effects of work input and cysteine on the overall score. The minimum level of work input that can produce the 35 points of overall score was 6.0 watt-hrs./lb. of work input level with 35 ppm of cysteine.

In summary, the RSM study on the combined effects of work input and cysteine levels indicated:

1. Undesirable effects of over- or under-mixing were clearly observed when the levels of work input and cysteine changed from their optimum levels.

2. Significant interaction between work input and cysteine was observed for specific volume.

3. Based on the analysis of the overall score, a combination of 7.0 watt-hrs./lb. of work input and 30 ppm of cysteine was recommended to minimize work input for operational convenience.

This estimated result was verified as shown in Plate 6. The specific volume was increased slightly and the grain score equalled those of the control.

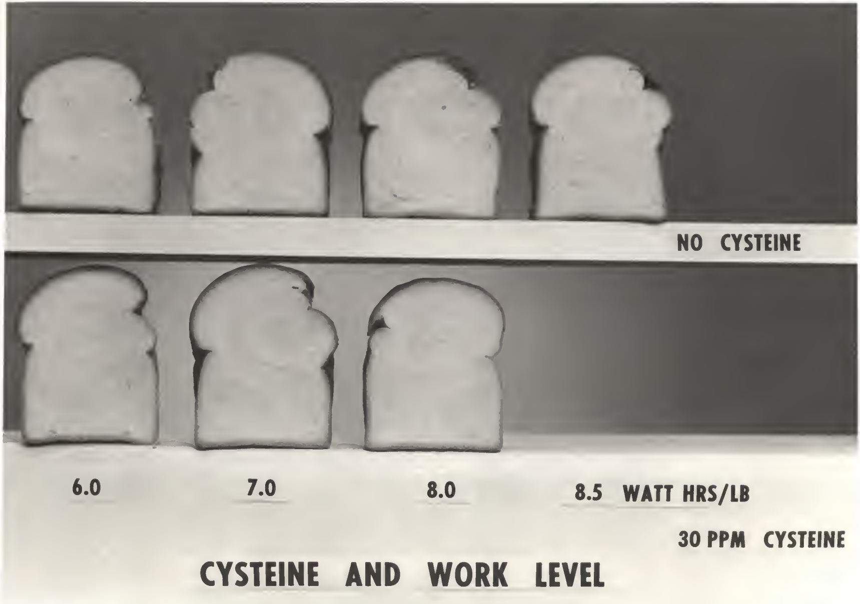


Plate 6. Effect of Cysteine and Work Input

SUMMARY AND CONCLUSION

An attempt to make acceptable U.S. type white pan bread by batch type mechanical dough development was carried out by optimizing important factors involved in the breadmaking process. The areas studied included the effect of processing conditions, oxidizing agents, dough strengtheners, and cysteine on this process. Response Surface Methodology and the Duncan Multiple Range Test were used; statistical analysis was obtained with a computer using the Statistical Analysis System (SAS) computer package.

The processing conditions: water absorption, work input and dough temperature were found to be of almost equal importance for obtaining optimum bread quality. Interactions were observed, especially between work input and dough temperature. Considering the estimated optimum and operational convenience, a combination of 60 % water absorption, 8.5 watt-hrs./lb. of work input, and 89 ^{o}F. dough temperature was recommended for this process.

A study of oxidizing agent systems showed that bromate was the most important oxidizing agent in this process. The effect of ascorbic acid depended on the levels of oxidizing agents used. It was beneficial only at high levels of combined oxidizing agents in this process, and its effect was more pronounced for grain structure than for specific volume.

The effect of ADA was questionable. A slight improvement in bread quality with ADA was observed only when combined with very low levels of bromate, but when used singly or combined with other oxidizing agents, its reaction was detrimental to bread quality. A combination of 30 ppm of bromate and 80 ppm of ascorbic acid gave the best result in the region covered by this experiment.

The effect of dough strengtheners on this process was not pronounced.

No significant differences were observed in specific volume and grain score compared to the control. However, their beneficial effect on crumb color and crumb firmness was obvious. There was no specific kind or level which outperformed the control significantly. However, relatively good performance of 0.5 % EMG/MG was observed in the bread characteristics studied.

The effect of cysteine on reducing work input in the dough system was carefully studied. The results showed that work input could be reduced from 8.5 watt-hrs./lb. to 6.0 watt-hrs./lb. with 40 ppm of cysteine without a significant decrease in bread quality. The best results were obtained with a combination of 7.0 watt-hrs./lb. of work input and 30 ppm of cysteine.

In conclusion, this study showed that it is possible to make acceptable U.S. type white pan bread by batch-type mechanical dough development. Even though a direct comparison with good quality bread made by conventional processes was not made, the large specific volume and the fine grain structure obtained were obviously similar to those made by the conventional processes.

Appendix 1. Processing Conditions

Number	Water* Abs.	Work* Input	Dough* Temp.	Specific Volume	Grain Structure	Crumb Color	Overall
1.	1	1	-1	6.53	8.1	54	34
				6.40	7.9	53	33
2.	1	-1	-1	6.05	7.9	48	20
				6.10	7.8	45	17
3.	1	-1	1	6.92	8.4	52	25
				6.97	8.2	54	25
4.	0	0	0	6.70	8.3	57	33
				6.65	8.4	55	33
5.	0	0	0	6.69	8.2	55	34
				6.75	8.4	52	32
6.	0	0	-1.682	5.80	7.4	45	23
				5.77	7.5	45	21
7.	1	1	1	6.55	7.1	37	28
				6.49	7.0	34	26
8.	0	-1.682	0	6.84	8.3	58	13
				6.80	8.4	61	12
9.	0	0	1.682	6.26	7.0	35	23
				6.30	6.8	36	25
10.	0	0	0	6.73	8.3	52	29
				6.65	8.4	54	31
11.	-1	-1	1	6.82	8.2	56	19
				6.90	8.2	55	16
12.	-1	-1	-1	6.21	7.6	48	18
				6.15	7.7	49	20
13.	0	1.682	0	6.50	7.2	42	35
				6.40	7.3	44	36
14.	-1	1	1	6.09	7.0	35	25
				6.15	6.8	38	26
15.	0	0	0	6.70	8.2	54	32
				6.80	8.5	53	30
16.	-1	1	-1	6.31	8.0	50	33
				6.25	8.0	52	35
17.	-1.682	0	0	6.65	8.3	56	24
				6.73	8.4	60	20
18.	0	0	0	6.87	8.2	56	30
				6.74	8.3	56	30
19.	1.682	0	0	6.80	8.4	54	28
				6.75	8.3	55	30
20.	0	0	0	6.71	8.3	57	33
				6.60	8.4	52	33

* Refer to Table 3.

Appendix 2. Oxidizing Agents

Number	Ascorbic* Acid	ADA*	Bromate*	Specific Volume	Grain Structure	Crumb Color	Overall
1.	1	1	-1	6.53	8.0	54	25
				6.40	7.8	53	22
2.	1	-1	-1	6.06	7.8	48	18
				6.10	7.7	45	18
3.	1	-1	1	6.92	8.3	52	32
				6.97	8.2	54	31
4.	0	0	0	6.70	8.2	57	29
				6.65	8.0	55	26
5.	0	0	0	6.69	8.2	55	28
				6.75	8.1	52	28
6.	0	0	-1.682	5.80	7.5	45	13
				5.77	7.5	45	12
7.	1	1	1	6.55	7.0	37	15
				6.49	6.7	34	14
8.	0	-1.682	0	6.84	8.6	58	34
				6.80	8.5	61	33
9.	0	0	1.682	6.26	7.0	35	12
				6.30	7.0	36	13
10.	0	0	0	6.73	8.0	52	27
				6.65	8.1	54	27
11.	-1	-1	1	6.82	8.2	56	30
				6.90	8.3	55	32
12.	-1	-1	-1	6.21	7.6	48	18
				6.15	7.7	49	18
13.	0	1.682	0	6.50	7.3	42	18
				6.49	7.2	44	16
14.	-1	1	1	6.09	6.8	35	18
				6.15	7.0	38	11
15.	0	0	0	6.70	8.2	54	29
				6.80	8.0	53	28
16.	-1	1	-1	6.31	8.0	50	23
				6.25	8.1	52	23
17.	-1.682	0	0	6.65	8.4	56	30
				6.73	8.5	60	32
18.	0	0	0	6.87	8.2	56	30
				6.74	8.0	56	27
19.	1.682	0	0	6.80	8.3	54	31
				6.75	8.4	55	31
20.	0	0	0	6.71	8.3	57	30
				6.60	8.0	52	26

* Refer to Table 4.

Appendix 3. Dough Conditioners

Number	Treatment*	Level**	Specific Volume	Grain Structure	Crumb Color	Crumb Firmness (1 day)	Crumb Firmness (4 day)
1.	0	0	6.95	8.7	55	130	207
			6.88	8.6	53	125	201
2.	1	1	7.08	8.6	60	116	211
			6.96	8.6	60	113	198
3.	1	2	6.92	8.7	65	102	180
			7.02	8.8	70	107	180
4.	1	3	6.90	8.7	65	114	176
			6.97	8.8	75	115	187
5.	0	0	7.03	8.3	53	134	195
			7.09	8.8	61	117	189
6.	2	1	7.15	8.6	64	116	173
			7.27	8.8	65	125	205
7.	2	2	6,92	8.5	55	120	202
			6.86	8.8	64	113	189
8.	2	3	6.99	8.7	72	95	202
			6.95	9.0	64	102	180
9.	0	0	6.75	8.3	60	123	194
			7.15	8.5	59	115	198
10.	3	1	7.13	8.5	58	115	191
			6.97	8.5	63	108	186
11.	3	2	7.15	8.6	68	107	171
			7.02	8.4	65	110	216
12.	3	3	7.17	8.8	73	115	172
			7.03	8.8	72	117	174
13.	0	0	6.90	8.8	60	124	255
			7.06	8.7	58	123	244
14.	4	1	6.58	8.6	64	111	200
			6.82	8.6	63	104	207
15.	4	2	6.70	8.8	70	104	185
			6.72	8.8	69	110	190
16.	4	3	6.96	8.2	66	85	170
			6.85	8.2	66	83	168

* Treatment: 0 = control; 1 = polysorbate 60/MG; 2 = SSL; 3 = EMG/MG; 4 = SMG/MG

Level: 0 = 0.00 %; 1 = 0.17 %; 2 = 0.34 %; 3 = 0.50 %

Appendix 4.. Work Input and Cysteine

Number	Work* Input	Cysteine*	Specific Volume	Grain Structure	Crumb Color	Overall
1.	0	0	6.90	8.5	65	34
			7.00	8.5	67	35
2.	-1	-1	6.62	8.2	65	28
			6.71	8.3	67	30
3.	-1	1	6.40	8.0	64	24
			6.58	7.8	62	24
4.	0	0	6.89	8.5	65	34
			7.10	8.6	67	36
5.	0	1.414	6.69	8.3	65	30
			6.53	8.2	66	27
6.	-1.414	0	6.92	8.6	68	35
			6.93	8.5	66	34
7.	1	1	6.52	8.3	67	28
			6.73	8.4	68	31
8.	0	0	6.92	8.6	66	35
			7.03	8.4	68	34
9.	1	-1	7.15	8.5	69	35
			7.17	8.4	71	34
10.	0	-1.414	6.91	8.0	69	29
			6.78	8.0	71	28
11.	0	0	6.94	8.5	66	34
			7.08	8.5	68	35
12.	-1.414	0	6.71	8.3	68	30
			6.68	8.2	66	29
13.	0	0	6.90	8.5	67	34
			6.85	8.6	65	34

* Refer to Table 12.

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STUDIES ON THE PRODUCTION OF U.S. WHITE PAN BREAD USING MECHANICAL DOUGH DEVELOPMENT

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AN ABSTRACT OF A MASTERS' THESIS

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Different aspects of U.S. type white pan breadmaking by mechanical dough development were studied with the Tweedy 35 high speed mixer. The effects of processing conditions, oxidizing agent system, dough strengtheners and the relationship between cysteine and work input were included. Response Surface Methodology and Duncan Multiple Range Test were used in the statistical evaluations.

Three processing conditions - water absorption, work input and dough temperature - were found to be closely related and their interactions were clearly observed, especially between work input and dough temperature. The recommended levels for this process were 60 % water absorption, 8.5 watt-hrs./lb. of work input and 89 ^{o}F. dough temperature. Study on the oxidizing agent system revealed that a combination of 30 ppm of bromate and 80 ppm of ascorbic acid gave the best result. Ascorbic acid was beneficial only in combination with other oxidizing agents, and no improving effect was observed with ADA. The effect of dough strengthener was not significant, but some improvement in bread quality was obtained from using 0.5 % Ethoxylated mono-diglyceride/mono-diglyceride. Cysteine was effective in reducing work input from 8.5 to 6.0 watt-hrs./lb. without seriously impairing bread quality. However, the best results were obtained with the combination of 30 ppm cysteine and 7.0 watt-hrs./lb. of work input.

The results of this study show a potential for using batch type mechanical dough development to produce acceptable U.S. type white pan bread.