SHORT-TIME BAKING SYSTEMS

by

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Major Professor

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Introduction

Approximately 45% of the bread produced commercially in the United States today uses some form of short-time or no-time fermentation process. Most agree that the bread produced by those processes differs in such attributes as flavor aud structure from that of conventional or long fermentation time processes. Initial rapid success of the short-time systems has leveled off over the last several years, presumably because of consumer resistance.

Most short-time baking systems have a minimum amount of fermentation. Presumably the need for fermentation has been replaced by high-speed mixing and high levels of strong oxidants. Although the factors affecting fermentation are well known, little work on the effect of various amounts of fermentation on bread characteristics has been reported. Therefore, this study on the effect of total fermentation on bread characteristics was undertaken with the hope that it would shed new light on the problems of short-time baking systems.

Because fermentation may be critical, we studied formulations of various short-time systems, attempting to hold fermentation constant. This allowed us to view certain of the critical relationships as a function of fermentation. Using response surface methodology (RSM) and computer technology we sought to better understand the relationships of $KBrO_3$, yeast concentration, and fermentation time of baking systems. Commercial short-time processes are using slightly higher amounts of yeast and relatively high levels (near the legal limit) of various combinations of oxidizing agents. Studies clearly showing the effects of those oxidant combinations on short-time systems were not found. Using RSM, and a

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commercial-type formula we studied the effects of certain oxidants, combinations of oxidants, and fermentation times.

Literature Review

Since the beginning of civilization, bread has constituted a major part of the human diet. Today in many parts of the world, it is relied upon for the main source of nutrition and energy. However, since automation of the baking industry, more specifically since the advent of short-time and continuous mixing processes, man has once again sacrificed quality for quantity.

Science tells us that a fermenting dough is a complicated biochemical system that must be balanced and optimized to produce the best results. Individual components and molecules that comprise the living organisms conform to the physical and chemical principles governing the behavior of matter. Furthermore, they react and interact in accordance with set principles.

For bread to have the best possible flavor aud texture, it must be produced under the most favorable conditions. That means, at least in part, that fermentation must be optimized. This paper will attempt to review the pertinent literature as it applies to the term "optimum fermentation."

Yeast--Fermentation. Yeast was discovered by Leuwenhoeck in 1680, but he did not associate them with the phenomena of fermentation. In fact, early researchers regarded fermentation process as one of spontaneous decay (1).

Quantitative studies of alcoholic fermentation were made around 1789, by Lavoisier, and later in 1810 by Gay-Lussac who reported the reaction $C_6H_{12}O_6$---------- $2C_2H_5OH + 2CO_2$. Pasteur, later observed that succinic acid, glycerol, aud other substances are normal by products of fermentation (2).

In 1897, Buchner discovered that a cell-free extract obtained from yeast was capable of fermentation (1, 3). The substance, called zymase, was regarded as an enzyme. By 1900 the Embden-Meyerhof scheme of glycolysis was derived and a variety of chemical entities were known to be produced during fermentation.

Today some of the products formed during fermentation are believed to actually come from bacteria. The major end-products, carbon dioxide and alcohol, are usually attributed to yeast, while lactic and acetic acid are considered products of bacteria (3). Robinson, et al. (4, 5) observed that the bacterial populations of preferments decreased during fermentation because of an inhibitory substance elaborated by yeast. But they also found that flavor was enhanced by certain bacteria. Although yeast cells far outnumber the bacteria in dough, the presence of those bacteria may be essential for optimum fermentation.

The yeast used in breadmaking is Saccharomyces cerevisiae. Yeast has three basic functions in breadmaking, A) leavening action by the production of carbon dioxide, B) flavor development as a consequence of the alcohols, acids, esters, the other flavor precursors that are formed, and C) dough development (6). The latter is the result of total fermentation.

The physiological parameters of yeast fermentation have been extensively studied and are perhaps the most understood part of the total complex system. Yeast will tolerate extremes of pH for short periods of time and possesses a fairly broad optimum range for fermentation (4.0-6.0) with a peak about 4.7 (2). Amos (7) explained the rapid increase in titrable acidity in fermenting dough as the initial CO_2 produced by the yeast dissolving in the aqueous phase. Thus, an actively fermenting system will be at optimum pH in a rather short time.

Temperature has a large effect upon the velocity of fermentation. Atkin et al. (2) reported that glucose fermentation was twice as fast at 35°C as at 25°C. Garver et al. (8) concluded that a temperature of about 38°C gave maximum specific activity under their broth fermentation conditions. Changing the temperature of the dough from 75°F to 95°F and proofing to height, Fisher and Halton (9) produced loaves of equal quality. Common practice today is to use a temperature that gives good dough handling properties.

The literature showing the importance of yeast nutrition for optimum has been reviewed by Atkin et al. (2), Oson and Johnson (10), and Reed and Peppler (11). For optimum yeast activity, sources of carbon and nitrogen and the minerals potassium, magnesium, zinc, sulfur, phosphorous, iron, and copper are required. External sources of the vitamins biotin and thiamine were shown to be necessary in a series of articles by Schultz et al. (12, 13, 14). Also, pyridoxine, calcium pantothenate and inositol should be supplied (11).

The use of yeast food containing oxidizing agents, yeast nutrients, minerals, and buffers has been common practice in the baking industry.

There is some question about the actual need of some of those components because dough ordinarily contains adequate minerals and buffers for yeast action (2). The material increase in gas production when flour is included in the system is shown in Fig. 1 (15).

Yeast is a very osmotolerant organism. High concentrations of sugar and salt will cause lower fermentation, but are not lethal to yeast. Little effect on fermentation rate in doughs has been noted when the sugar concentration was varied from 0-6% (16, 17).

Carbohydrates--Fermentation. Sugars in bread dough arise from three sources (18): sugar originally present in the flour, sugars produced by the action of enzymes, and those intentionally added as dough ingredients. The sugars of greatest importance in breadmaking are the disaccharides sucrose and maltose, the monosaccharides glucose and fructose, and the glucofructans (19). The total amount of those sugars in flour has been shown to be about 1.2% (20). The baking quality of brews made with glucose or sucrose has been shown to be equal (21). Because of the potent invertase enzyme of yeast, sucrose is converted almost immediately to glucose and fructose. The yeast ferments glucose at a slightly faster rate than fructose (2). Maltose, when in the presence of fructose and glucose, is not fermented appreciably. Yeast enzymes are constitutive for glucose and fructose, and must adapt if maltose is to be fermented. If maltose is the only added sugar (external addition or produced by malt) there is an appreciable drop in the rate of gas production after the indigenous fructose and glucofructan are exhausted but before the yeast enzymes adapt to maltose (17, 21).

Fig. 1. Gassing power for no flour, flour and certain other fractions.

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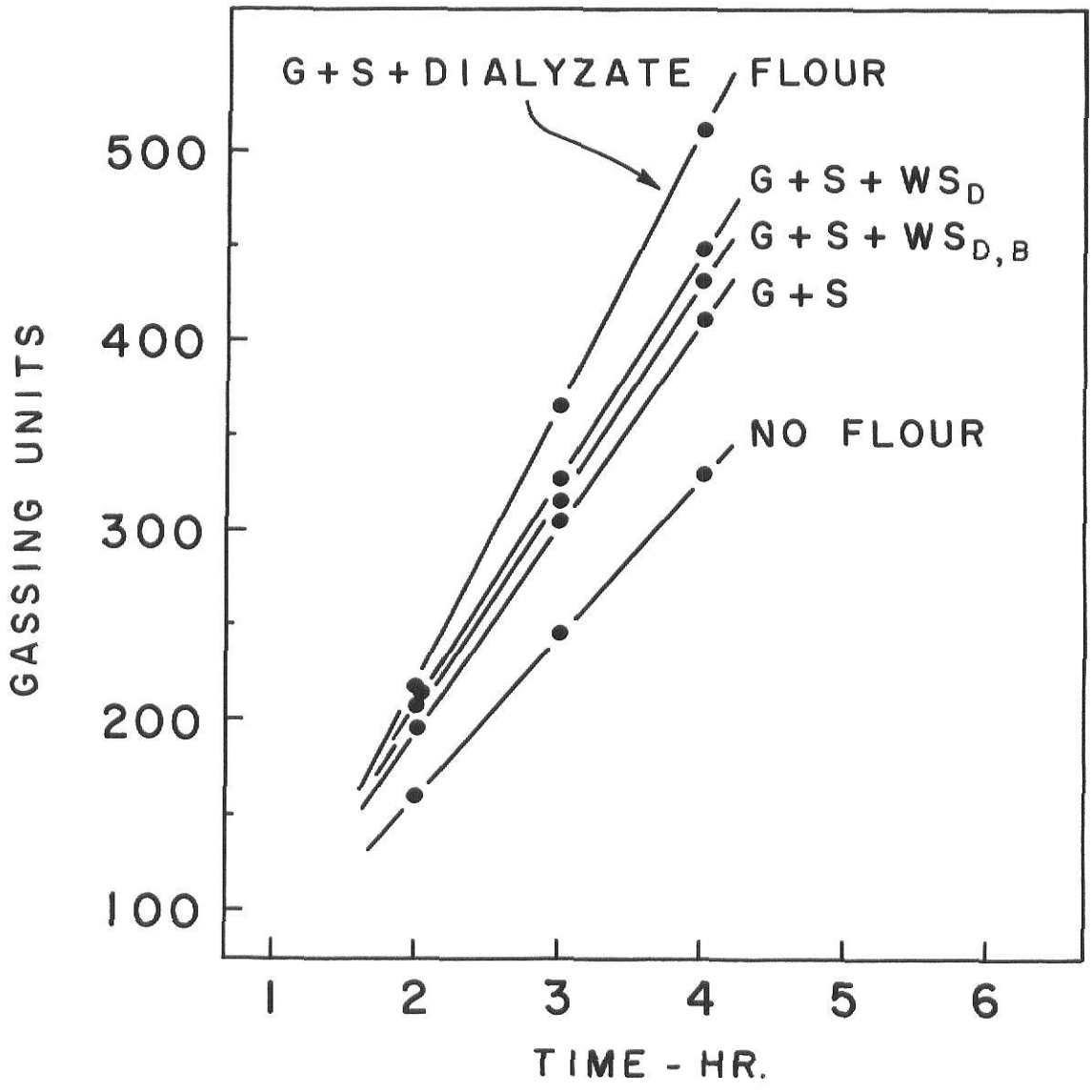

G + S + DIALYZATE
FLOUR
G + S + WS$_D$
G + S + WS$_{D,B}$
G + S
NO FLOUR
GASSING UNITS
500
400
300
200
100
1
2
3
4
5
6
TIME - HR.

Starch is the major component of flour and varys from 54-72% of the total on a dry basis. Wheat flour contains amylase enzymes which hydrolyze susceptible starch. Beta-amylase is considered to be a saccharifying amylase because of its ability to produce maltose from the non-reducing end of linear starch chains. Thus, beta-amylase will completely saccharify the straight chain amylose fraction and the terminal chains (to the first branch point) of the branched chain amylopectin fraction. The high molecular weight residue resulting from beta-amylase attack on amylopectin is termed ß-limit dextrin. Alpha-amylase, the starch dextrinizing enzyme, attacks both amylose and amylopectin in a more random fashion, releasing straight chain glucose groupings capable of being attacked by beta-amylase (7). Sound ungerminated wheat contains only small amounts of alpha-amylase but relatively large amounts of beta-amylase (23). However, upon germination there is a tremendous increase of alpha-amylase while total beta-amylase remains essentially constant.

Munz and Bailey (24) established that alpha-amylase was the diastatic component responsible for increased dough mobility, increased gas production of doughs, and the increase in loaf volume caused by malt supplementation. Until that time, flour quality was partially judged on its diastatic power. However, as the amounts of alpha- and beta-amylase present in a dough could be adjusted rather easily by the controlled supplementation of flour with malted-flour, that variable among flours was eliminated and allowed for more pertinent studies of flour quality.

A large percentage of the starch granules in flour are undamaged. Beta-amylase does not attack undamaged starch and hydrolyzes damaged starch slowly. Alpha-amylase attacks damaged starch more vigorously than undamaged starch and is capable of attacking starch that is not sufficiently damaged to be susceptible to beta-amylase (18).

The customary concept of the significance of amylase action in doughs is related to the production of fermentable sugars. The importance of this saccharification depends largely on the level of sugar added to the dough. Excellent bread can be produced with no added sugar if malt supplementation is adequate (25). Most U.S. bread is produced with 6-8% added sugar. Because the end-product of amylase action, maltose, is regarded as inhibitory to amylase action (23), and maltose is not fermented if other sugars are available (19), the role of amylases would appear small in bread production. However, addition of malt supplement even in the presence of excess sugar does improve loaf volume (25). The nature of that improvement appears outside the scope of this review.

Other Additives--Fermentation. Salt, which is a required dough constituent under the Standards of Identity, has a stabilizing effect on yeast fermentation, has a toughening effect on gluten, and acts as a retardant to proteolytic activity (26). According to Walden and Larmour (21), salt has the effect of prolonging the time over which reasonably high gassing rates occur.

Non-fat dry milk solids' value to fermentation appears to be its buffering ability in relation to both hydrogen-ion concentration and oxidation requirement. The importance of milk solids in buffering the

oxidation requirement. The importance of milk solids in buffering the oxidation requirement and therefore decreasing the detrimental effects of over-bromation was shown by Finney and Barmour (27). In addition to its buffering action, milk solids also increased the requirement for oxidant. Difficulties were encountered with the traditional levels of milk (4%) in the initial continuous breadmaking systems. Frequently, the use of more than 1-2% dry milk solids resulted in loss of loaf volume and overall bread quality (28). This possibly is the result of adding to the already high levels of oxidation required for continuous bread.

Fermentation--Dough Development. Thus far, we have discussed the relationships which effect fermentation. After a dough is mixed to optimum, it has a certain unique structure. After a dough has undergone optimum fermentation it has a completely new and unique structure. The change in structure is the result of fermentation. Fermentation development is a separate and different entity from that of developing a dough in the mixer (29).

The chemical effects of fermentation are still mostly a mystery. Fermentation appears to have a pronounced effect on the nature of the gluten complex. There is a balance between gluten's ability to form thin extensible films and of the rheological properties of the dough which allows for maximum retention of gas. This may be the result, or combination of proteolysis, fermentation by-products, and hydrogen ion concentration. All these factors alter the colloidal behavior of gluten, and account for the balance of estensibility and elasticity properties found in a fermented dough.

It has not been proven that proteolytic action in a fermenting dough significantly affects dough properties. Amos (7) showed a slow but progressive liberation of amino nitrogen in a dough. Amos emphasized that, although the quantity of amino nitrogen set free from protein by proteolysis in a dough is small, it does not necessarily follow that the physical changes are also small. That viewpoint has been supported by Skovholt and Bailey (30) and others.

There are many chemicals produced (Table 1) as a result of fermentation and/or baking (2, 31, 11). Certain of those chemicals or their interaction products may have a pronounced effect on dough development. Pyler (31) sums up by stating that dough maturity represents the sum total of all the reactions that take place during fermentation.

Carbon dioxide, lactic acid, and the assimilation of ammonia, which may liberate strong acids, probably are the most significant factors responsible for the decrease in hydrogen-ion concentration (32). The reduction of pH has a very pronounced effect on the hydration and swelling of the gluten, reaction rate of enzymes, oxidation-reduction processes, and on various chemical reactions involving organic salts (33).

Oxidation requirements generally increase with protein content. The correlation is, however, low because of the variation in mixing requirements within a variety and the interrelation of mixing time and oxidation requirement (27). Also, the oxidation requirement is related apparently to fermentation, because sponge-doughs require less oxidant than straight doughs. Many things can be said in reference to the oxidation-reduction process, particularly the sulphydryl-disulfide theory. The following

Table 1. Compounds reported to be produced during yeast fermentation.

Organic Acids		Alcohols	Aldehydes and Ketones	Carbonyl Compounds
Butyric	Acetic	Ethanol	Acetaldehyde	Furfural
Succinic	Lactic	n-Propanol	Formaldehyde	Methional
Propionic	Formic	Iso-butanol	Isovaleraldehyde	Glycoxal
n-Butyric	Valeric	Amyl alcohol	n-Valderaldehyde	3-Methyl butanol
Isobutyric	Caproic	Isoamyl alcohol	2-Methyl butanol	2-Methyl butanol
Isovaleric	Caprylic	2,3-Butanedial	n-Hexaldehyde	Hydroxymethyl furfural
Heptanoic	Isocaproic	β-Phenyl ethyl alcohol	Acetone	
Pelargonic	Capric		Propionaldehyde	
Pyruvic	Lauric		Iso-butyraldehyde	
Palmitic	Myristic		Methyl ethyl ketone	
Crontonic	Hydrocinnamic		2-Butanone	
Itaconic	Benzylic		Diacetyl	
Levulinic			Acetain	

quote sums up what is fact to-date: "The following premises have not been conclusively demonstrated. A) The sulfhydryl radical is potentially capable of undergoing a crosslinking reaction to form disulfide bridges between protein chains: B) such a reaction would govern rheological properties of dough: C) the formation of the disulfide bond is the chemical basis of the improving action of oxidants (34)."

Fermentation-Flavor. Organoleptic properties include all the chemical and physical characteristics of the food that are capable of producing olfactory (smell), gustatory (taste), tactual (touch), and visual (sight) sense impressions in the consumer (31). There is general agreement among scientist and consumers alike, that bread flavor is related to fermentation. A summation of all the aspects of fermentation. A summation of all the aspects of fermentation mentioned thus far would produce bread with optimum flavor. Bread made by the continuous mix process is generally considered inferior to that produced by sponge or straight dough procedures in both structure and taste. This may be the result of unbalanced ingredients and non-optimum fermentation.

Materials and Methods

Flour Samples. An experimentally-milled, hard-winter-wheat flour composite (RBS-73A), a hard-spring-wheat flour composite (SWS-72), and a commercially-milled, hard winter wheat flour were used as standards. In addition, three hard winter wheats (Gage, Winoka, and Shawnee) and two hard spring wheats (Chris and Red River 68) grown in 1971 at Garden City,

S.D., and Presho, S.D., were selected for ranges in protein contents, mixing times, other physical dough properties, and oxidation requirements.

Baking Test. Water absorption, mixing time, and potassium bromate were optimized in the straight-dough, bread-baking procedure (35). The formula included 100 g. flour (14% m.b.), 1.5 g. NaCl, 6 g. sucrose, 3 g. shortening, 4 g. nonfat milk solids, 0.75 g. malted wheat flour, and 2 g. yeast (5). Doughs were punched after 105 and 155 min. and panned after 180 min. of fermentation. Proof time was 55 min. and loaves were baked 24 min. at 218°C. Loaves were weighed as they came from the oven, and volumes were determined by rape-seed displacement. The effects of fermentation time, yeast concentration, and $KBrO_3$ on bread characteristics was studied with a standardized procedure using a 70 min. fermentation time, 7.2% yeast concentration, 60 ppm $KBrO_3$ punching at 40 and 60 min., and a proof height of 7.2 mm. Fermentation time was varied $\pm$ 10 min., $KBrO_3$ $\pm$ 30 ppm, yeast concentration $\pm$ 1.0% from the standard procedure. The formulas other ingredients were maintained at constant levels equal to that of the standard baking procedure. For 60 min. fermentation time, punching was set at 35 and 52 min., proportionate to the decrease in fermentation time. Loaves were proofed to a height that varied depending on yeast concentration. With 80 min. fermentation time, punching was set at 47 and 69 min., again proportionate to the decrease in fermentation time. Similarly loaves were proofed to a height that depended on yeast coucentratiou. Since the yeast concentration determined the rate of gas production, doughs containing 6.2% yeast were proofed 2 mm higher than and doughs containing 8.2% yeast were proofed 2 mm lower than those containing 7.2% yeast. Those variable proof heights were used to enable

us to compensate for variation in oven spring that results from the rate of gas production in the oven.

The commercial type formula used to evaluate certain oxidants, combination of oxidants, and fermentation times was 4.0% yeast, with the other ingredients unchanged from the standard 3-hour formula. Loaves were proofed to height (7.8 mm). Proof times were 79, 49, and 37 min., for 0, 30, and 60 min. fermentation times respectively.

Analytical Procedures. Gassing powers on 10 g. flour were determined at 30°C. with a gauge-type pressure meter (National Mfg., Lincoln, Nebraska). All baking ingredients, except yeast, were combined and brought to temperature in a water bath. Then yeast was dispensed at 2-min. intervals and the doughs mixed by hand for approximately 1 min. Flour protein, moisture, and ash contents were determined by standard AACC methods (36). Mixograms were made on the 10-g. mixograph as described by Finney and Shogren (37). Breadmaking absorptions were used for the mixograph.

RSM Analysis. For statistical analysis where 3 variables are involved, the technique of Response Surface Methodology (RSM) described by Cockran and Cox (38) was used. This technique involves taking certain data points from a factorial design and solving for a response surface. The computor program then prints out the data as contour maps. The equation for the response surface was the Taylor expansion series for 3 variables as follows: $Y = Bo + B_1X_1 + B_2X_2 + B_3B_3 + B_{11}X_1^2 + B_{22}X_2^2 + B_{33}X_3^2 + B_{12}X_1X_2 + B_{13}X_1X_3 + B_{23}X_2X_3$.

Results and Discussion

Preliminary studies indicated that balancing formulae for fermentation times below 45 min. would be difficult and probably impractical. The difficulties in producing bread similar to that obtained with our standard formula decreased, however, when we increased fermentation time from 45 to about 70 min., so we selected 70 min. of fermentation time to begin this study.

Formulation of Short-time Baking Systems. With fermentation time at 70 min., we varied yeast levels from 2 to 10%; 2% was optimum for 180 min. of fermentation. As yeast concentration was increased above 7.2%, doughs became progressively stiff, bucky, and generally over-developed and the breads appeared over developed. However, as yeast concentration was decreased below 7.2%, doughs and breads became progressively under-developed. We varied sugar, salt, and malted wheat flour with the 70-min. fermentation time. However, no changes in amounts of those ingredients were required to produce breads comparable to those obtained by the standard procedure.

Punchings after 105 and 155 min. of fermentation (180 min. total) were decreased to 40 and 60 min., respectively. Proof time also required a proportionate decrease from 55 to 21½ min. Deviating from those times altered the internal or external appearance of the loaves. When yeast was increased from 2 to 7.2%, water absorption remained constant and mixing time increased only 1/8 min.

When fermentation times of 180 (2% yeast) and 70 min. (7.2% yeast) were applied to the three standard flours, and potassium bromate was varied (Fig. 2), 70 min. of fermentation required three times more $KBrO_3$ than did 180 min. Loaves for the two fermentation times were indistinguishable by loaf volume, internal or external appearance, and flavor.

Wheat Variety Testing with 70-min. Fermentation. Because the three standard flours gave comparable breads with both 180- and 70-min. fermentation times, we studied applicability of the 70-min. fermentation time for wheat quality research and variety testing.

When the 70-min. fermentation time was applied to three hard winter and two hard spring wheat varieties, grown at two locations, bread loaf volumes and other loaf characteristics were fully equal to those for 180 min. (Table 2). Flour protein contents of samples from Presho were 3.1 to 4.4% greater than those from Garden City. Mixograms (Fig. 3) illustrate the wide variation in mixing and other physical dough properties of the varieties studied. The potassium bromate requirement increased by a factor of 3.0, and yeast concentration by a factor of 3.6 when fermentation time was decreased from 180 to 70 min.

Yeast Concentration vs. Fermentation Time. After yeast concentration was established for fermentation times of 180 and 70 min., 120 min. and 45 min. times were studied. Breads comparable to those produced with the standard 180-min. fermentation time were obtained for 3.5% yeast and 120 min. and for 12% yeast and 45 min. The 12% yeast and 45-min. fermen-

Fig. 2. Loaf volumes and $KBrO_3$ requirements for the three standard flours using 180 (o) and 70 (o) min. fermentation.

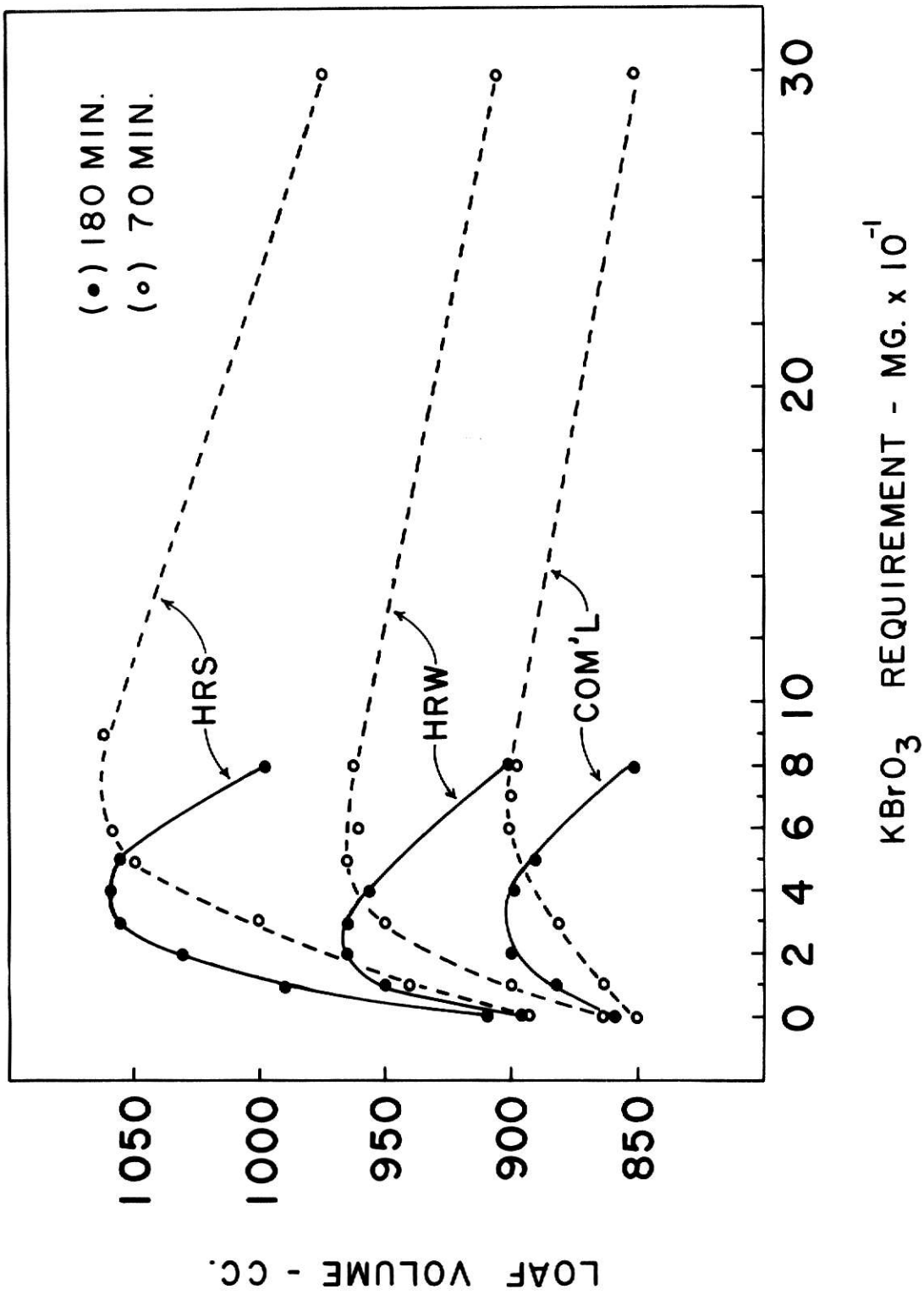

(•) 180 MIN.
(○) 70 MIN.
HRS
HRW
COM'L
LOAF VOLUME - CC.
1050
1000
950
900
850
0 2 4 6 8 10 20 30
KBrO3 REQUIREMENT - MG. x 10-1

Table 2. Chemical, physical, and baking (180 vs. 70 min. fermentation) Data for flours of hard winter and hard spring wheat varieties harvested at Garden City and Presho, South Dakota in 1971. [a/]

Location and Sample	Protein %	H_2O Abs. %	Mix time min.	$KBrO_3$ 180 min.	$KBrO_3$ 70 min.	$KBrO_3$ 180 min.	$KBrO_3$ 70 min.
Garden City, S.D.							
Gage, W[b/]	11.8	62.6	2 1/2	25	75	917	912
Winoka, W	10.8	61.7	4 3/4	20	60	915	912
Shawnee, W	11.6	67.1	3 3/4	20	60	987	995
Chris, S	12.4	69.2	4	30	90	960	972
Red River 68, S	11.6	63.2	7	0[e/]	10	903	925
Red River 68[c/]	11.6	63.2	3 3/4	10	30	997	999
Presho, S.D.							
Gage	15.1	68.0	4	25	75	1117	1118
Winoka	14.4	67.9	5 3/8	25	75	1109	1130
Shawnee	14.7	70.6	5	15	45	1126	1132
Chris	16.8	69.6	3 5/8	25	75	1219	1195
Red River 68	15.6	70.0	14	0[f/]	--	1010	--
Red River 68[d/]	15.6	70.0	5	10	30	1175	1200
Standard Composites							
Commercial, W	11.8	66.0	3 3/4	25	75	900	910
RBS-73A, W	12.7	66.8	4	20	60	968	973
SWS-72, S	13.9	67.1	3 1/2	25	75	1060	1055

a/ Data expressed on a 14% m.b.

b/ W and S, abbreviations for hard winter and hard spring wheats, respectively.

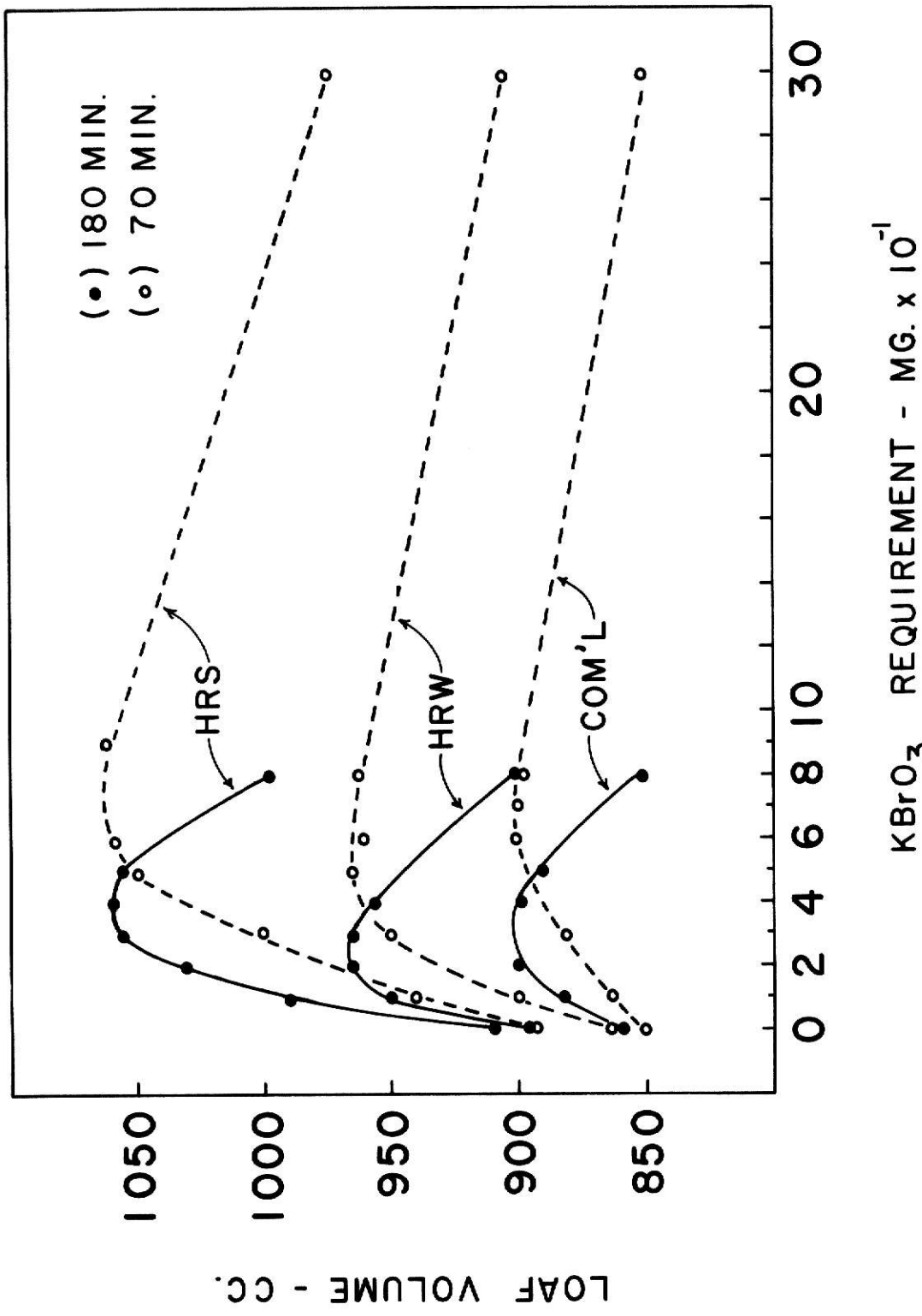
c/ 60 p.p.m. cysteine - HCl added before mixing.

d/ 120 p.p.m. cysteine · HCl added before mixing.

e/ Bread appeared overoxidized the equivalent of at least 10 p.p.m. of potassium bromate.

f/ Bread appeared overoxidized the equivalent of at least 20 p.p.m. of potassium bromate.

Fig. 3. Mixograms of the three hard winter wheats (Gage, Winoka, and Shawnee) and two hard spring wheats (Chris and Red River 68) grown at Presho and Garden City, S.D., in 1971.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HRS
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COM'L
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1050
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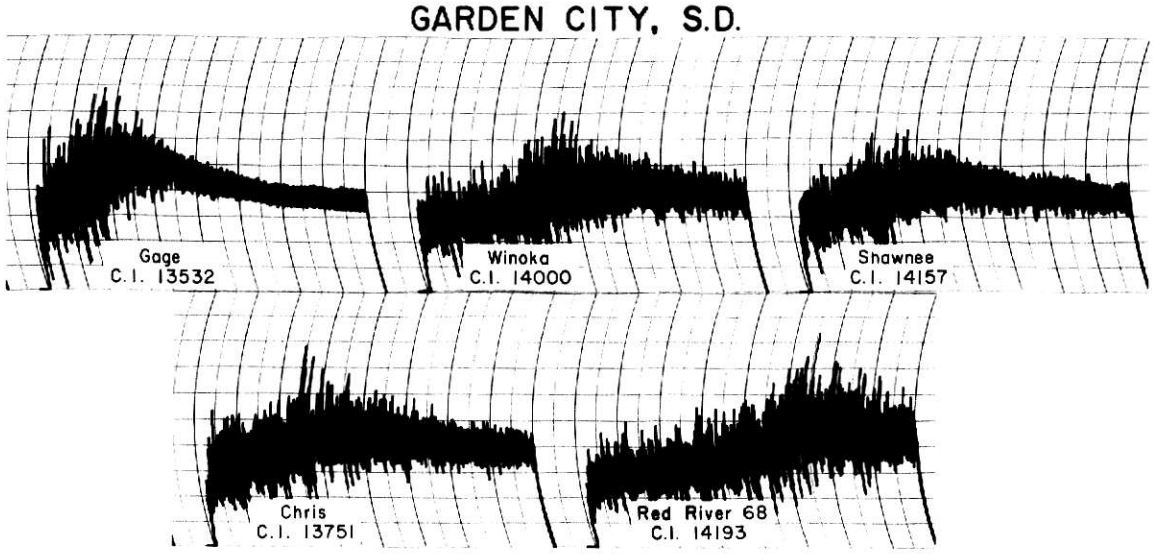

GARDEN CITY, S.D.
Gage
C.I. 13532
Winoka
C.I. 14000
Shawnee
C.I. 14157
Chris
C.I. 13751
Red River 68
C.I. 14193

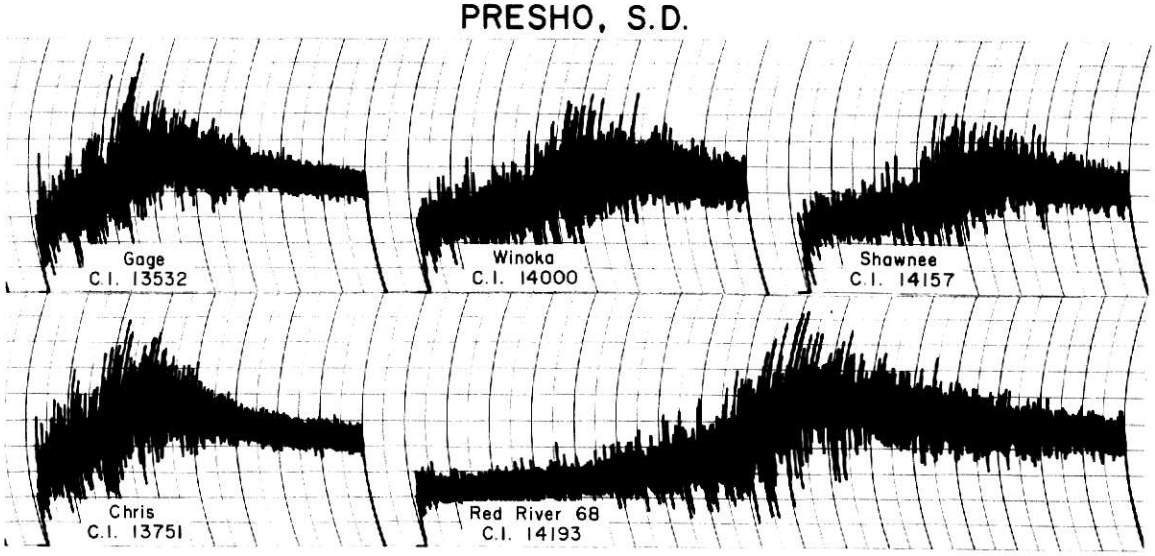

PRESHO, S.D.
Gage
C.I. 13532
Winoka
C.I. 14000
Shawnee
C.I. 14157
Chris
C.I. 13751
Red River 68
C.I. 14193

Fig. 3. Mixograms of the three hard winter wheats (Gage, Winoka, and Shawnee) and two hard spring wheats (Chris and Red River 68) grown at Presho and Garden City, S.D., in 1971.

tation time produced optimum loaf volume and other external properties, but the crumb grain was slightly brownish, the crumb was noticeably wet, and the flavor was bitter or yeast-like. The general relationship of yeast coucentration and fermentation time for optimum bread is summarized by Fig. 4. Fermentation times appreciably less than 70 min. require undesirable amounts of yeast.

Fermentation Time vs. $KBrO_3$ Requirement. The baking formulae remained the same for all fermentation times given in Fig. 3, except for $KBrO_3$ requirement. The $KBrO_3$ requirements of the commercial flour for 180, 120, 70, and 45 min. fermentation times were 20, 30, 60, and 130 p.p.m., respectively (Fig. 5).

Plotting (Fig. 6) $KBrO_3$ requirements and corresponding fermentation times for all flours (Table 2 and Fig. 5) established the general relation between those two factors. As fermentation time decreases, $KBrO_3$ requirement increases. Specifically, each flour's requirement increases by a factor of 1.5 for 120 min. of fermentation, 3.0 for 70 min., and 6.0 for 45 min. of fermentation. That flours vary in $KBrO_3$ requirement when using 180 min. of fermentation is well established (39). Related hyperbolic curves for different flours suggest that as $KBrO_3$ requirement approaches zero for 180 min. of fermentation, it also approaches zero for any fermentation time between 180 and 45 min.

Both Red River 68 flours appeared "gluten-bound" to various degrees. Neither flour exhibited a bromate requirement with 180-min. fermentation time. However, once the "gluten-bound" character was alleviated by 60 and 120 p.p.m. of cysteine hydrochloride (Table 2), the bromate requirement for the 180- and 70-min. systems was 10 and 30 p.p.m., respectively.

Fig. 4. Yeast concentrations and fermentation times required to produce optimum breads with the standard commercial flour.

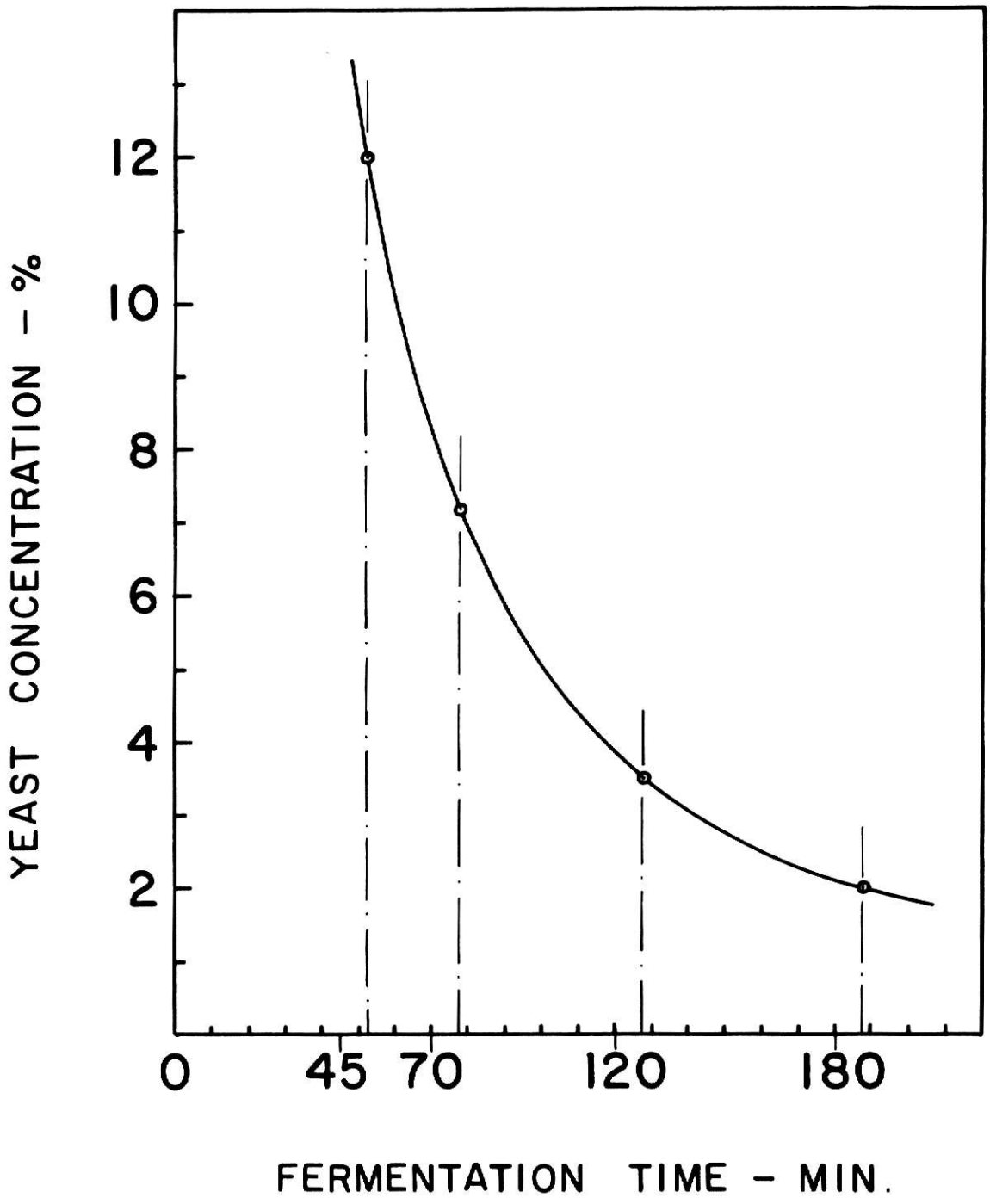

YEAST CONCENTRATION - %
12
10
8
6
4
2
0
45
70
120
180
FERMENTATION TIME - MIN.

Fig. 5. $KBrO_3$ requirements and fermentation times required to produce optimum breads with the standard commercial flour.

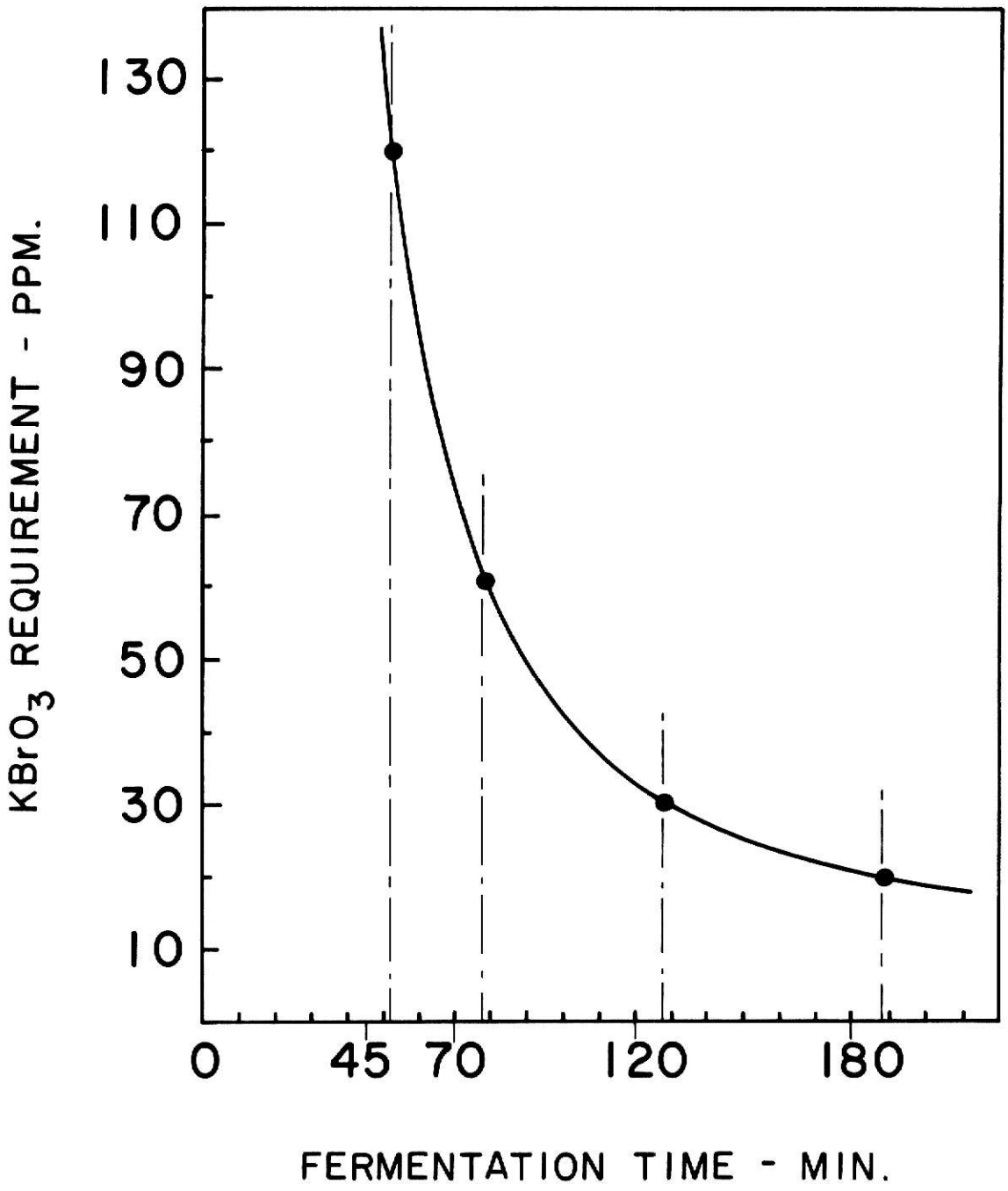
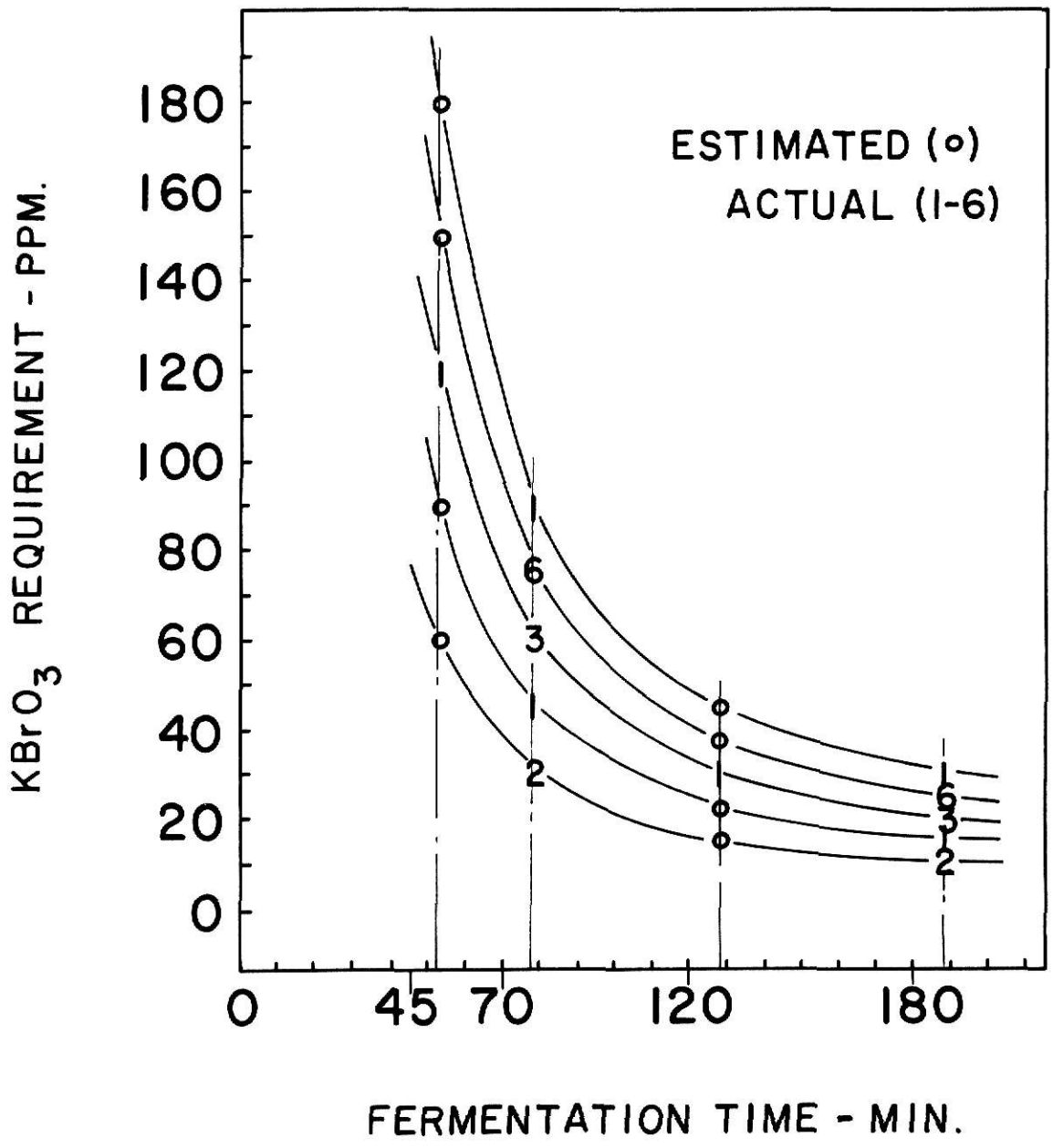

130
110
90
70
50
30
10
KBrO3 REQUIREMENT - PPM.
0
45
70
120
180
FERMENTATION TIME - MIN.

Fig. 6. $KBrO_3$ requirements and fermentation times for all flours in Table 2. Number of samples plotted for a given amount of $KBrO_3$ is identified by number 1 to 6.


ESTIMATED (o)
ACTUAL (1-6)
KBrO3 REQUIREMENT - PPM.
180
160
140
120
100
80
60
40
20
0
0
45
70
120
180
FERMENTATION TIME - MIN.

Gassing Power. Observations of the dough size suggested that the total gas retained at punchings during fermentation was constant, even though total fermentation time varied. Those observations, together with the equality of bread properties, including crust color, suggested that total gas production remained constant as fermentation time varied.

Gassing power data were obtained for 2, 7.2, and 12% yeast concentrations (Fig. 7). During the baking procedure, 8 min. of fermentation takes place between when ingredients are added and dough mixing ends. A line drawn vertical to the x-axis at 188 (180 + 8) min. fermentation intersects the 2% yeast curve at 350 gassing units. Nearly identical gassing power values are produced at 53 (45 + 8) and 78 (70 + 8) min. fermentations. Thus, the fermentation activity of the 3 yeast systems was essentially constant.

Proof Time vs. Fermentation Time. Proof time for the 70-min. fermentation time was 21½ min. As proof times were increased beyond 21½ min., loaves appeared over-proofed, and had shell tops or double breaks. Proofing for less than 21½ min. gave low volume and an underdeveloped appearance. Optimum proof times for 120- and 45-min. fermentation times were 36½ and 12 min., respectively.

Those proof times establish a general relationship of fermentation time to optimum proof time (Fig. 8). Proof time decreases in proportion to the decrease in fermentation time from 180 to 70 min. At 45-min. fermentation a proof time of 12 min. (rather than 13.75 min. as the broken part of the regression line suggests) was optimum for 12% yeast.

Fig. 7. Gas production for 2, 7.2, and 12% yeast concentrations related to fermentation times.

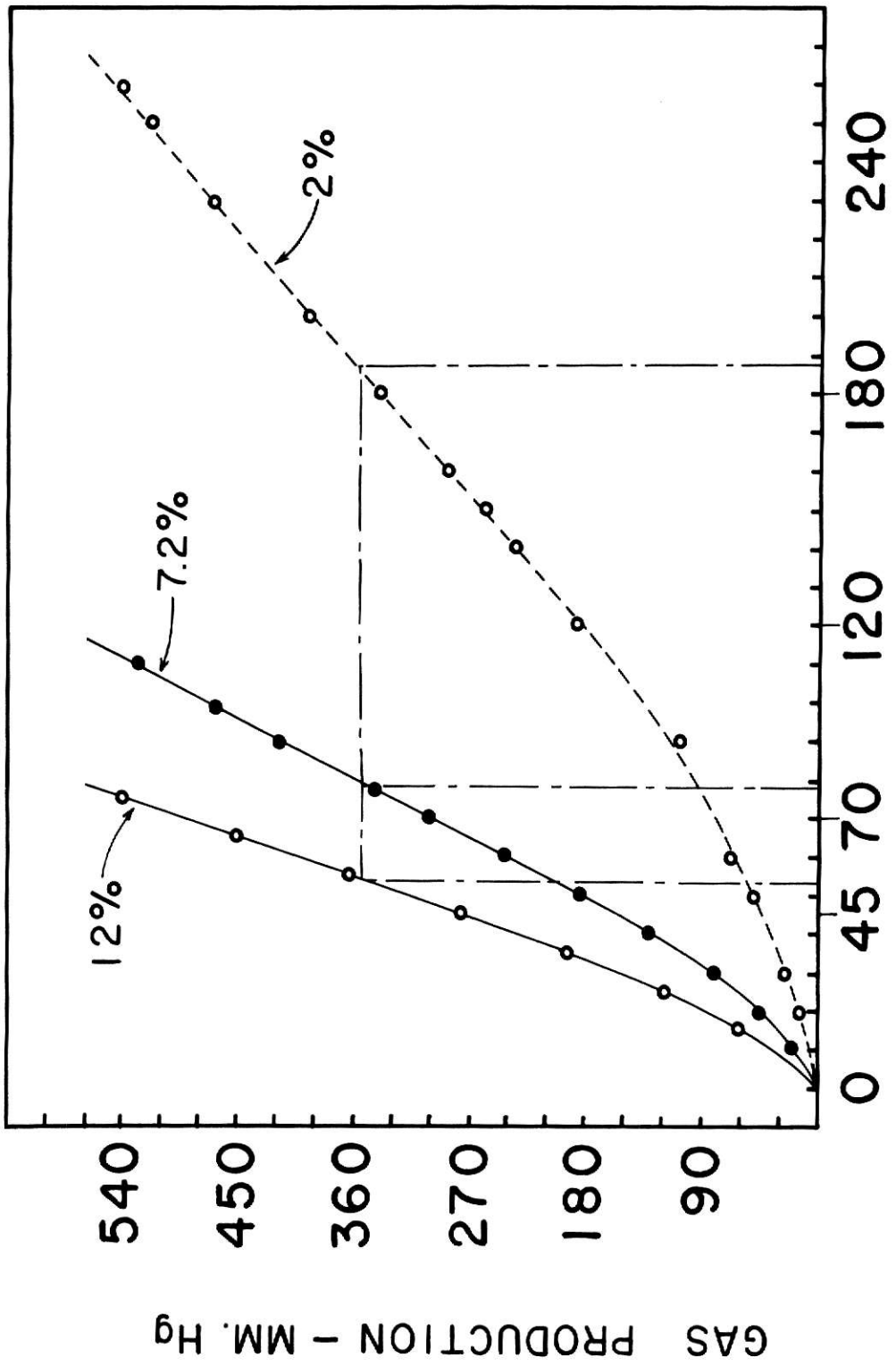
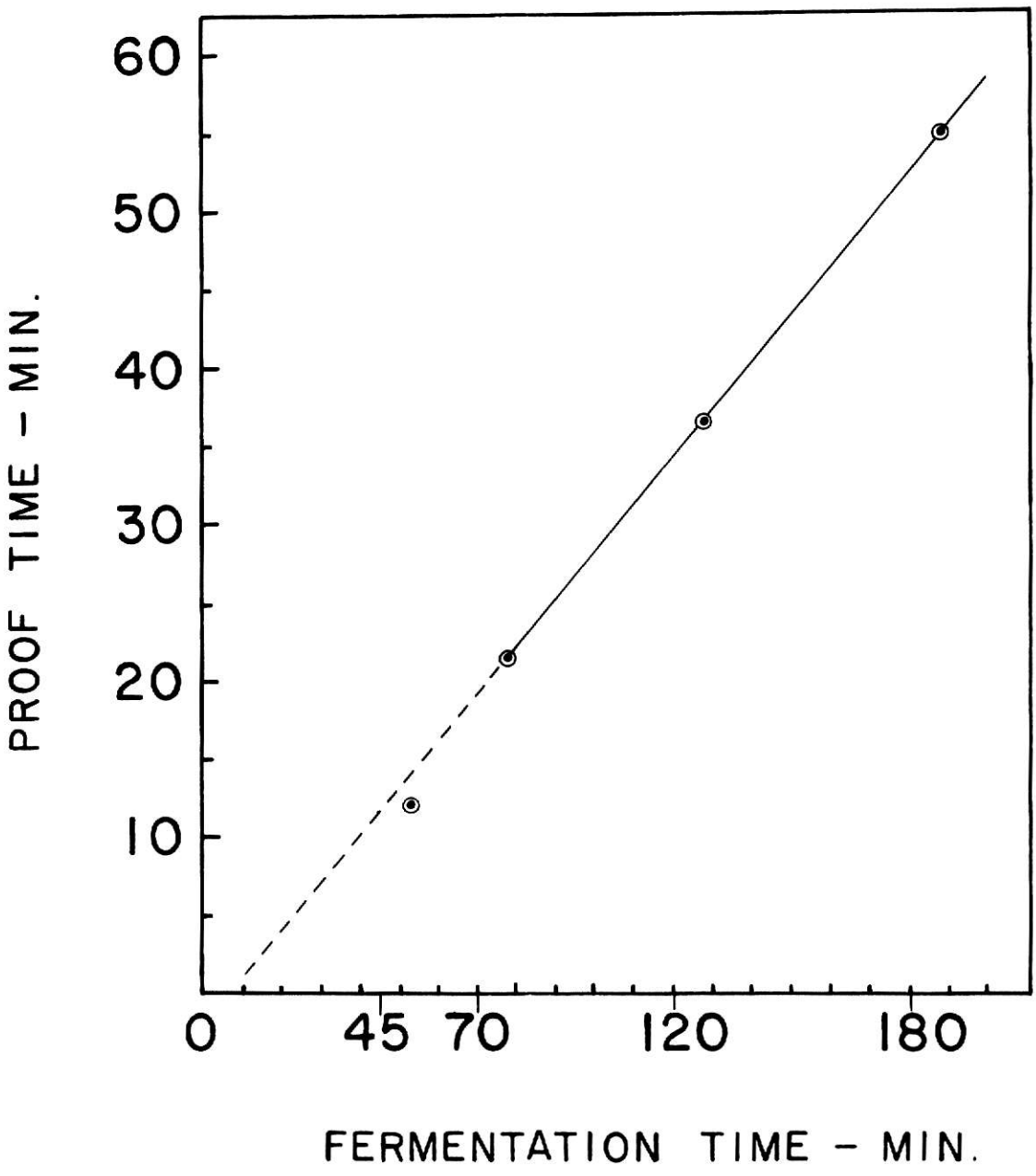

GAS PRODUCTION – MM. Hg
540
450
360
270
180
90
0
45
70
120
180
240
FERMENTATION TIME – MIN.
2%
7.2%
12%

Fig. 8. Proof and fermentation times for optimum bread.


60
50
40
30
20
10
PROOF TIME - MIN.
0
45
70
120
180
FERMENTATION TIME - MIN.

Fermentation activity begins when the yeast and sugar solutions come into contact 8 min. before mixing is completed and ends a few min. after the dough is placed in the oven, or as soon as the oven temperature inactivates the yeast. We estimate that time to be about 8 min. for the pup doughs baked at 218°C. When 16 min. was added to each of the fermentation times studied, and those sums were added to the respective proof times used, the total fermentation times of the systems studied were 251, 107½, and 73 min. instead of 180, 70, and 45 min. Taking the gassing power data (Fig. 7) and drawing (Fig. 9) a line parallel to the x-axis to intersect the 2% yeast curve at 251 min. of fermentation, we note that the line intersects the 7.2% and 12% yeast curves at about 107½ and 73 min., respectively, the identical total fermentation times used in baking.

Effect of Fermentation Time, Yeast Concentration, and $KBrO_3$ on Bread Characteristics. Studies with the short-time baking systems established an increasing $KBrO_3$ requirement with decreasing fermentation time and increasing amount of yeast. To better understand the interactions of yeast concentration, fermentation time, and $KBrO_3$ requirement on bread characteristics, a surface response study of those variables was undertaken.

Loaf Volume. The relationship between yeast concentration, $KBrO_3$, and fermentation time as measured by loaf volume, is summarized in Table 3 and Figs. 10, 11, and 12. At all times, the data indicate that the highest loaf volumes were obtained at the lowest (6.2%) level of

Fig. 9. Gas production for 2, 7.2, and 12% yeast related to total fermentation times (measured 8 min. before mixing ends until 8 min. after baking begins).

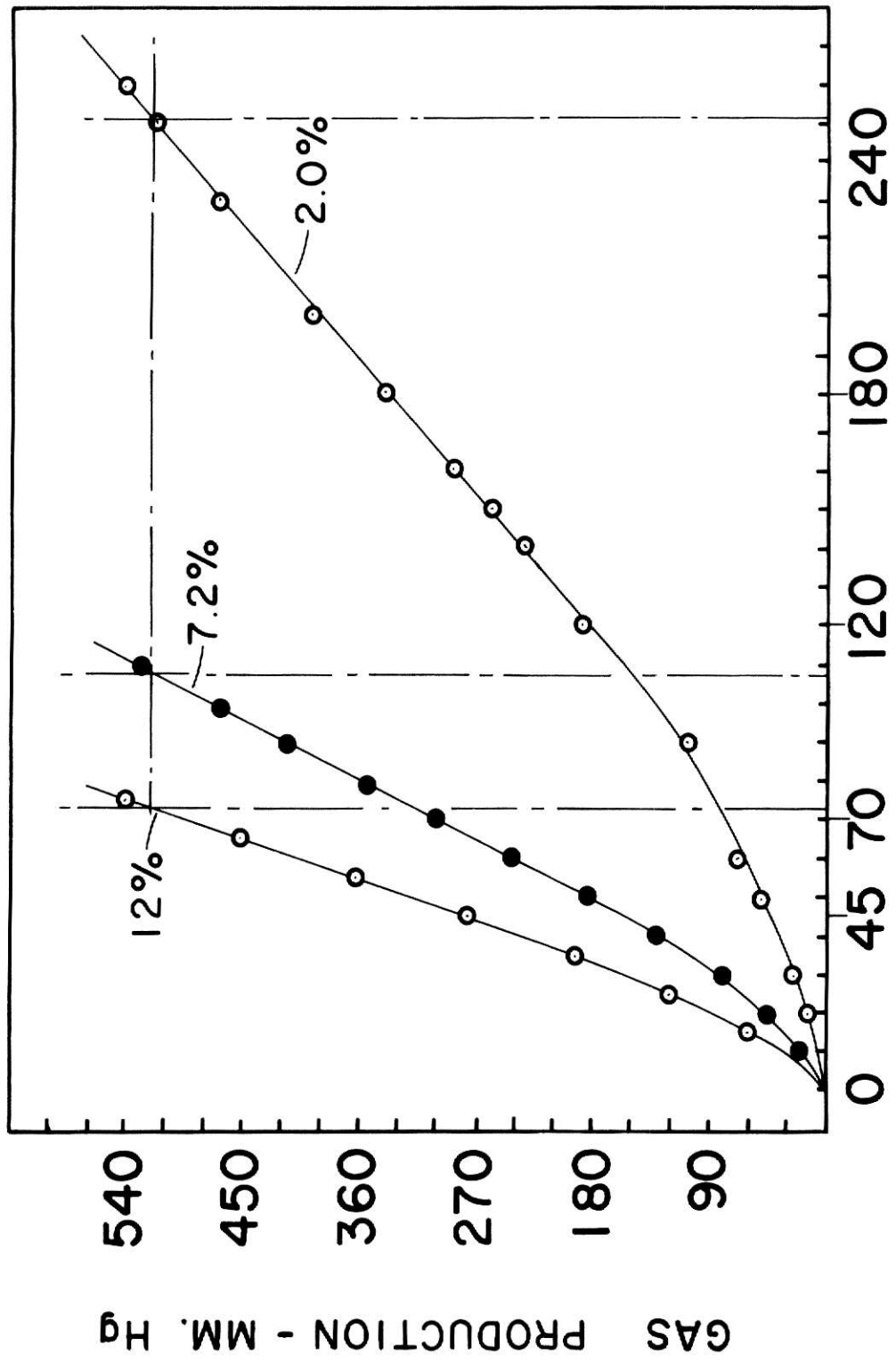

GAS PRODUCTION - MM. Hg
540
450
360
270
180
90
0
45 70
120
180
240
FERMENTATION TIME - MIN.
12%
7.2%
2.0%

Table 3. Loaf volume (cc) data points for the RSM study of the effect of fermentation time, yeast concentration, and $KBrO_3$ on bread characteristics.

Yeast conc.	$KBrO_3$	Fermentation times		
		60	70	80
%	ppm	min.	min.	min.
6.2	30		900	
"	60	997		973
"	90		1026	
7.2	30	962		947
"	60		995 1010 1015	
"	90	1002		887
8.2	30		962	
"	60	984		930
"	90		910	

Equation for response surface. $Y = 1004.1 - 20.0\ x_1 - 26.0\ x_3 - 25.3\ x_2^2 - 31.3\ x_3^2 - 17.0\ x_1 x_2 - 25.0\ x_2 x_3$ where: X_1 = yeast concentration, x_2 = fermentation time, and $x_3 = KBrO_3$. All B values included in the equation are significant at the 5% level.

Fig. 10. Contour plot of loaf volume (K = 950 cc, L = 975 cc, M = 100 cc, N = 1025 cc) for yeast concentrations and $KBrO_3$ levels at 60 min. fermentation time.

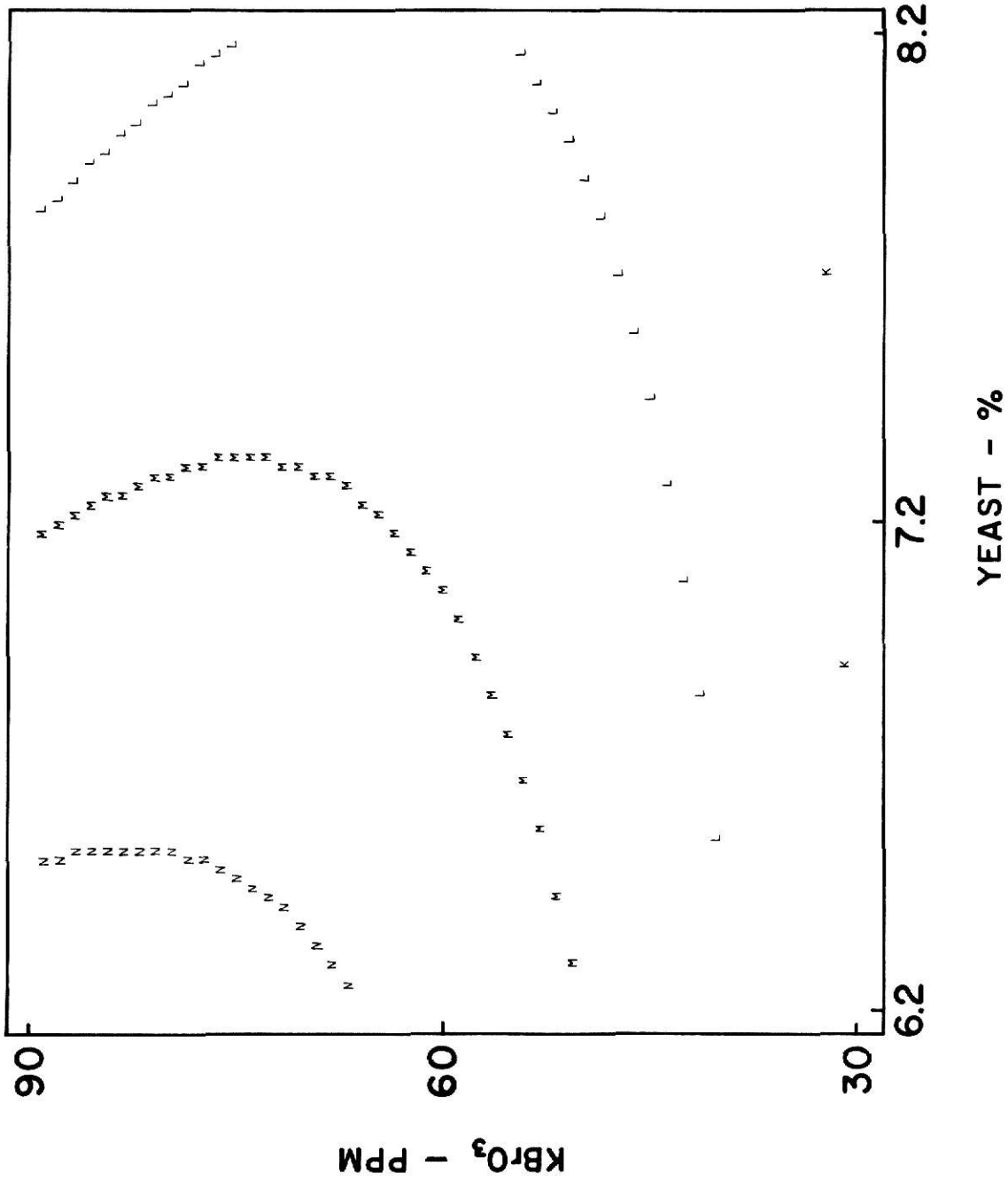

90
60
30
KBrO3 – PPM
6.2
7.2
8.2
YEAST – %

Fig. 11. Contour plot of loaf volume (K = 950 cc, L = 975 cc, M = 100 cc) for yeast concentration and $KBrO_3$ levels at 70 min. fermentation times.

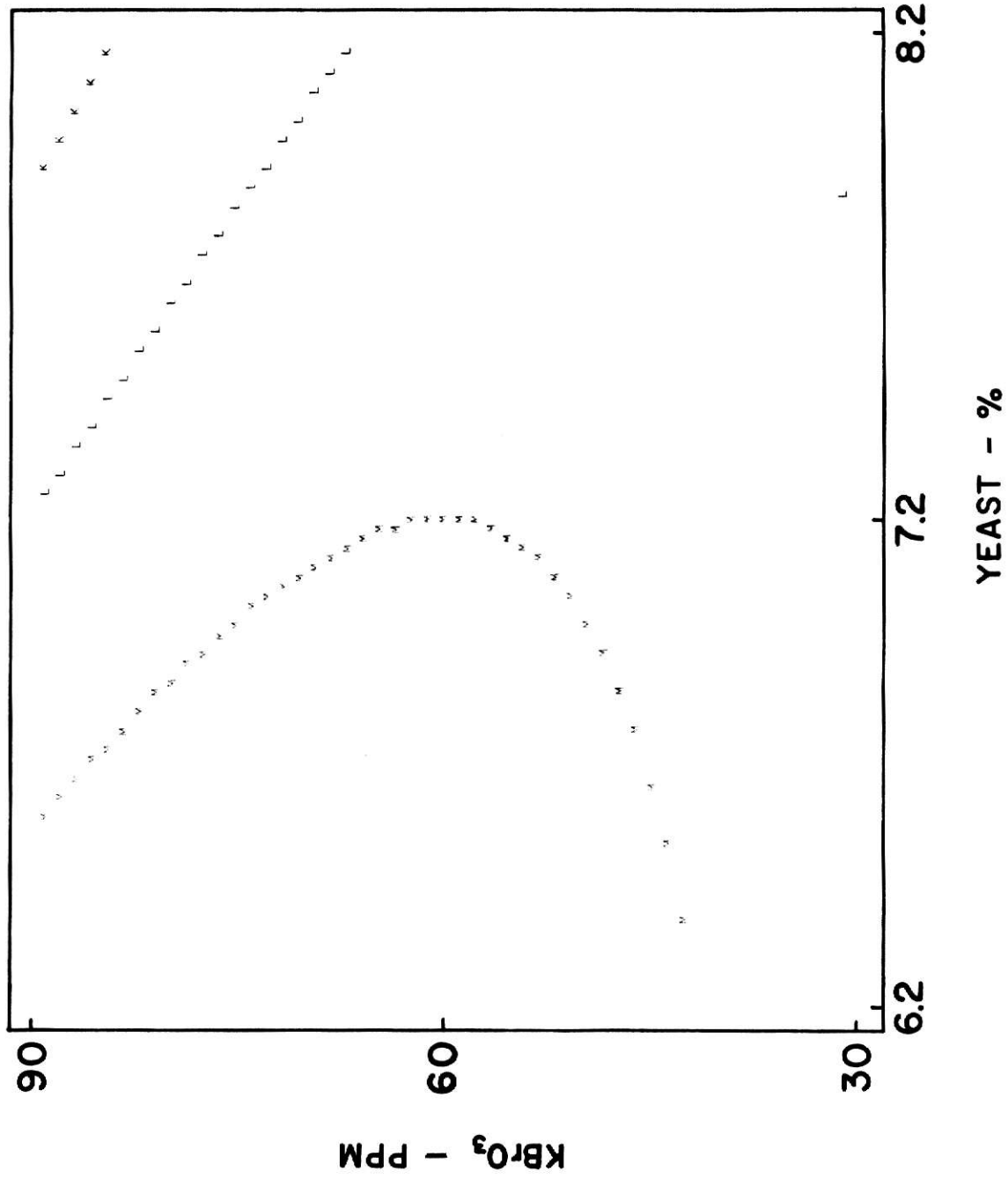
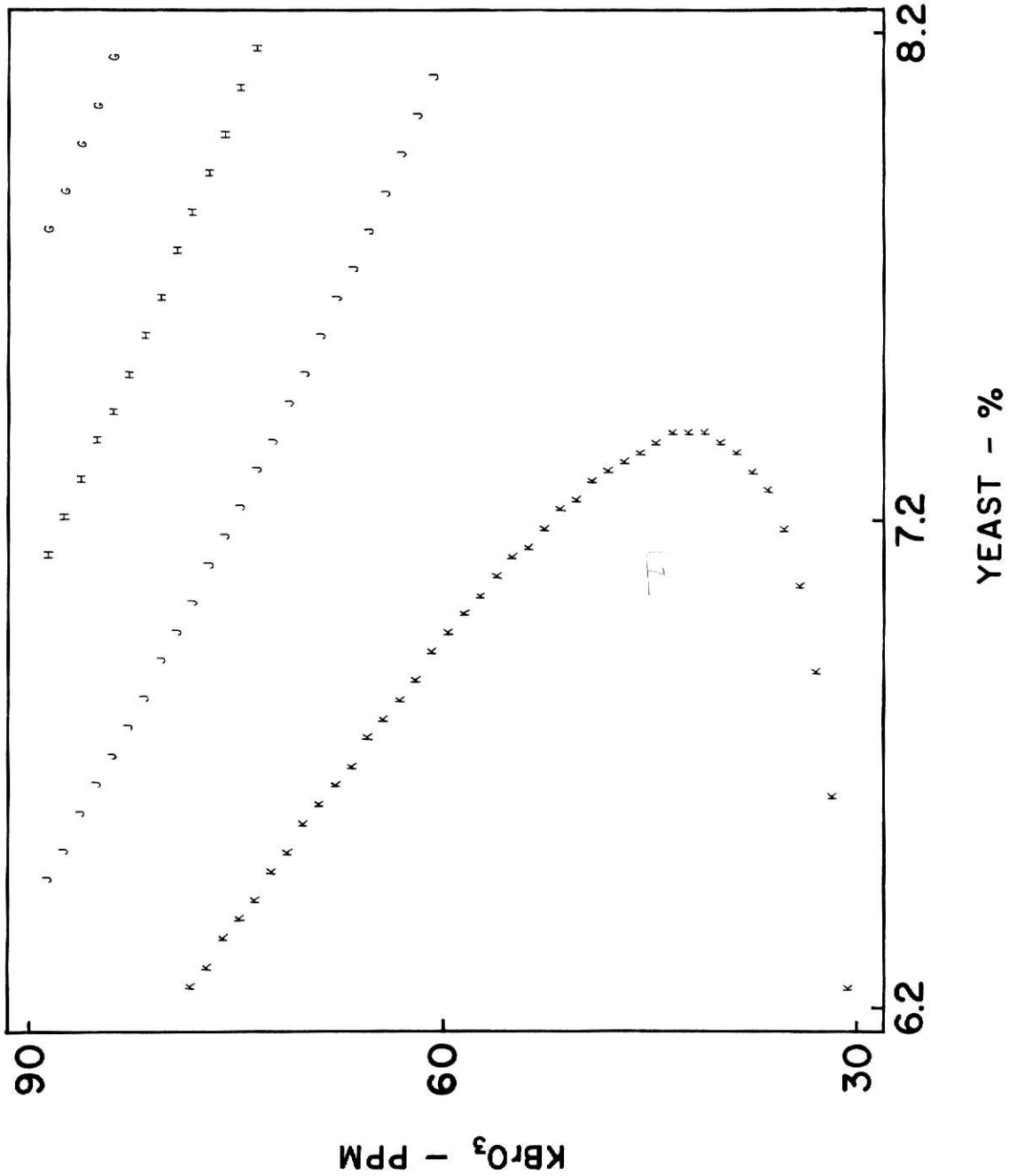

90
60
30
KBrO3 - PPM
6.2
7.2
8.2
YEAST - %

Fig. 12. Contour plot of loaf volume (G = 875 cc, H = 900 cc, J = 925 cc, K = 950 cc) for yeast concentrations and $KBrO_3$ levels at 80 min. fermentation times.


90
60
30
6.2
7.2
8.2
KBrO3 – PPM
YEAST – %

yeast. At 6.2% yeast, as fermentation time decreased, the $KBrO_3$ requirement increased from approximately 50 ppm to 90 ppm. The $KBrO_3$ requirement appears to be directly proportional to fermentation activity (fermentation time x yeast concentration).

Oxidation Characteristics. The oxidation appearance of the bread (Table 4 and Figs. 13, 14, and 15) varied with the fermentation time. At a given yeast concentration, as fermentation time decreased, it required more $KBrO_3$ to maintain an oxidation appearance. At the lower fermentation time (60 min.) oxidation characteristics became insensitive to changes in yeast concentration.

Proof Time. Generally proof time would vary only with yeast concentration. However, as shown in Table 5, Fig. 16) the longer fermentation times in combination with higher yeast concentration apparently exhausted the sugar supply and gave longer proof times. The effect of those longer proof times on the other data is not clear. At the center point (7.2% yeast, 70 min. fermentation time, and 60 ppm $KBrO_3$) of the experiment we are near the point where proof time start increasing.

Effect of Certain Oxidants, Combination of Oxidants, and Fermentation Time with a Commercial Type Formula. As noted earlier, commercial short-time processes use about 3-4% yeast and combinations of oxidizing agents. The most common oxidant combinations are $KBrO_3$:KIO_3 and $KBrO_3$:Azodicarbanamide (ADA). Fermentation times vary from "no-time" in the continuous system to about 30 min. in many "short-time" systems. Preliminary studies indicated

Table 4. Oxidation data points for the RSM study of the effect of fermentation time, yeast concentration, and $KBrO_3$ on bread characteristics.

Yeast conc.	$KBrO_3$	Fermentation times		
		60	70	80
%	ppm	min.	min.	min.
6.2	30		4[a/]	
"	60	4.5		5.5
"	90		6	
7.2	30	3		6
"	60		5	
"	90	5		8.5
8.2	30		4.5	
"	60	4.5		7.5
"	90		7.5	

Equation for response surface. $Y = 5.4 + .5\ x_1 + 1.2\ x_2 + 1.3\ x_3 + .5\ x_1\ x_3$ where: x_1 = yeast concentration, x_2 = fermentation time, $x_3 = KBrO_3$. All B values included in the equation are significant at the 5% level.

a/ 5.0 equals optimum oxidation and each whole unit, above (over oxidized) or below (under oxidized) is equivalent to 30 ppm $KBrO_3$.

Fig. 13. Contour plot of oxidation appearance (B = 3.0, E = 4.5, F = 5.0) for yeast concentration and $KBrO_3$ level at 60 min. fermentation time. A value of 5.0 equals optimum oxidation and each whole unit above (over oxidized) or below (under oxidized) is equivalent to 30 ppm $KBrO_3$.

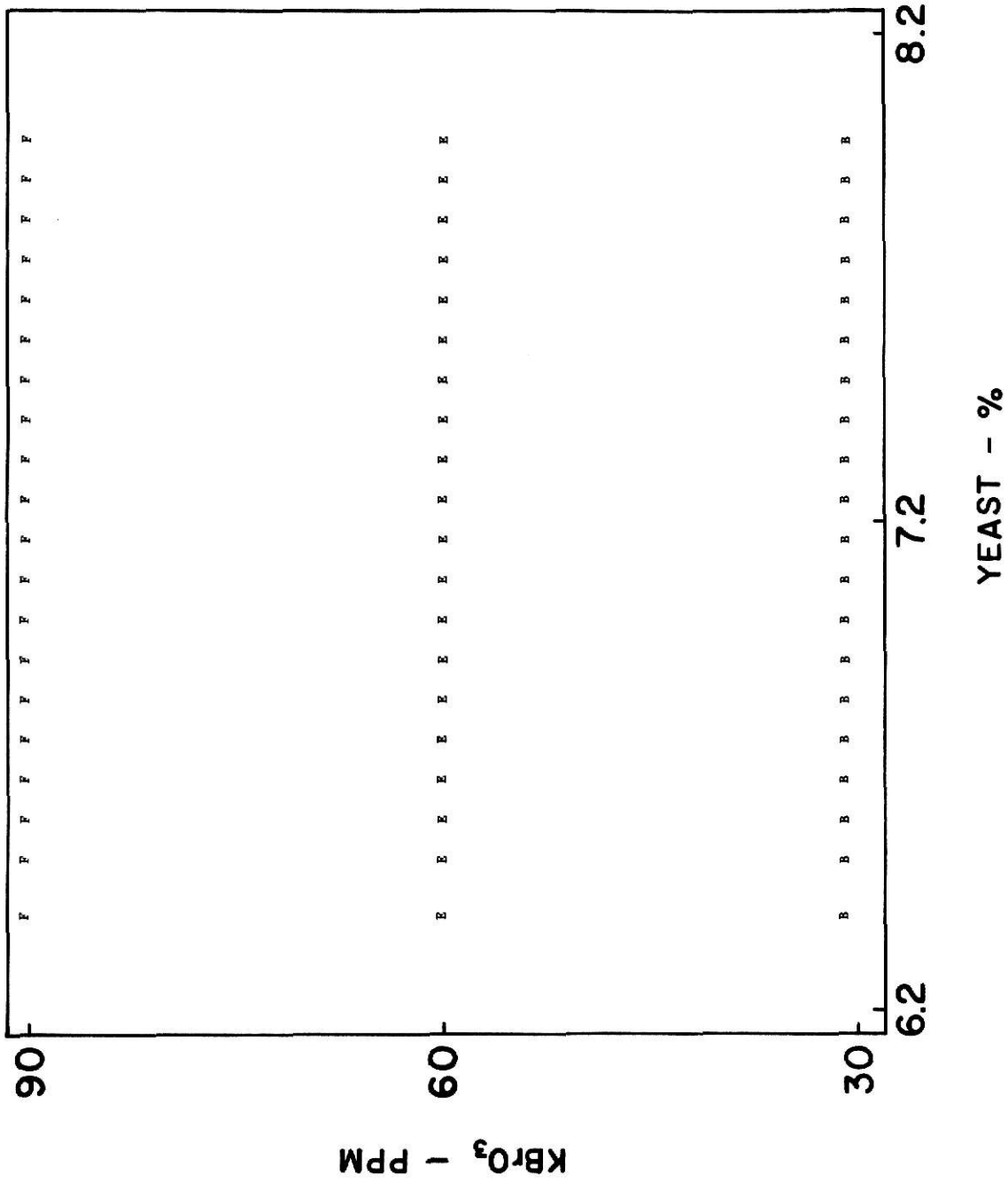

90
60
30
KBrO3 - PPM
6.2
7.2
8.2
YEAST - %

Fig. 14. Contour plot of oxidation appearance (D = 4.0, E = 4.5, F = 5.0, G = 5.5, H = 6.0, J = 6.5, K = 7.0) for yeast concentrations and $KBrO_3$ level at 70 min. fermentation time. A value of 5.0 equals optimum oxidation and each whole unit above (over oxidized) or below (under oxidized) is equivalent to 30 ppm $KBrO_3$.

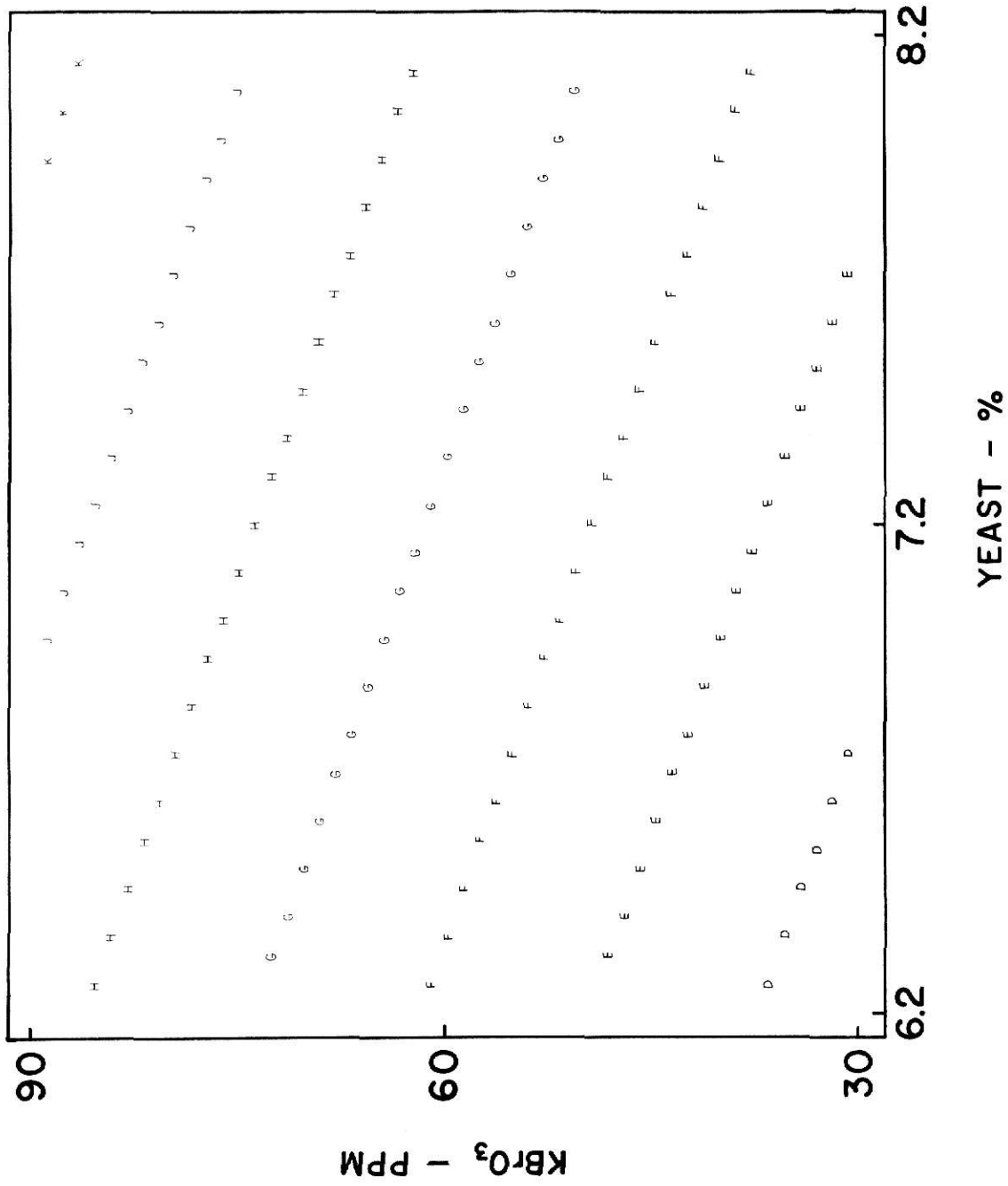

90
60
30
6.2
7.2
8.2
KBrO3 – PPM
YEAST – %

Fig. 15. Contour plot of oxidation appearance (F = 5.0, G = 5.5, H = 6.0, J = 6.5, K = 7.0, L = 7.5, M = 8.0, N = 8.5) for yeast concentration and $KBrO_3$ levels at 80 min. fermentation time. A value of 5.0 equals optimum oxidation and each whole unit above (over oxidized) or below (under oxidized) is equivalent to 30 ppm $KBrO_3$.

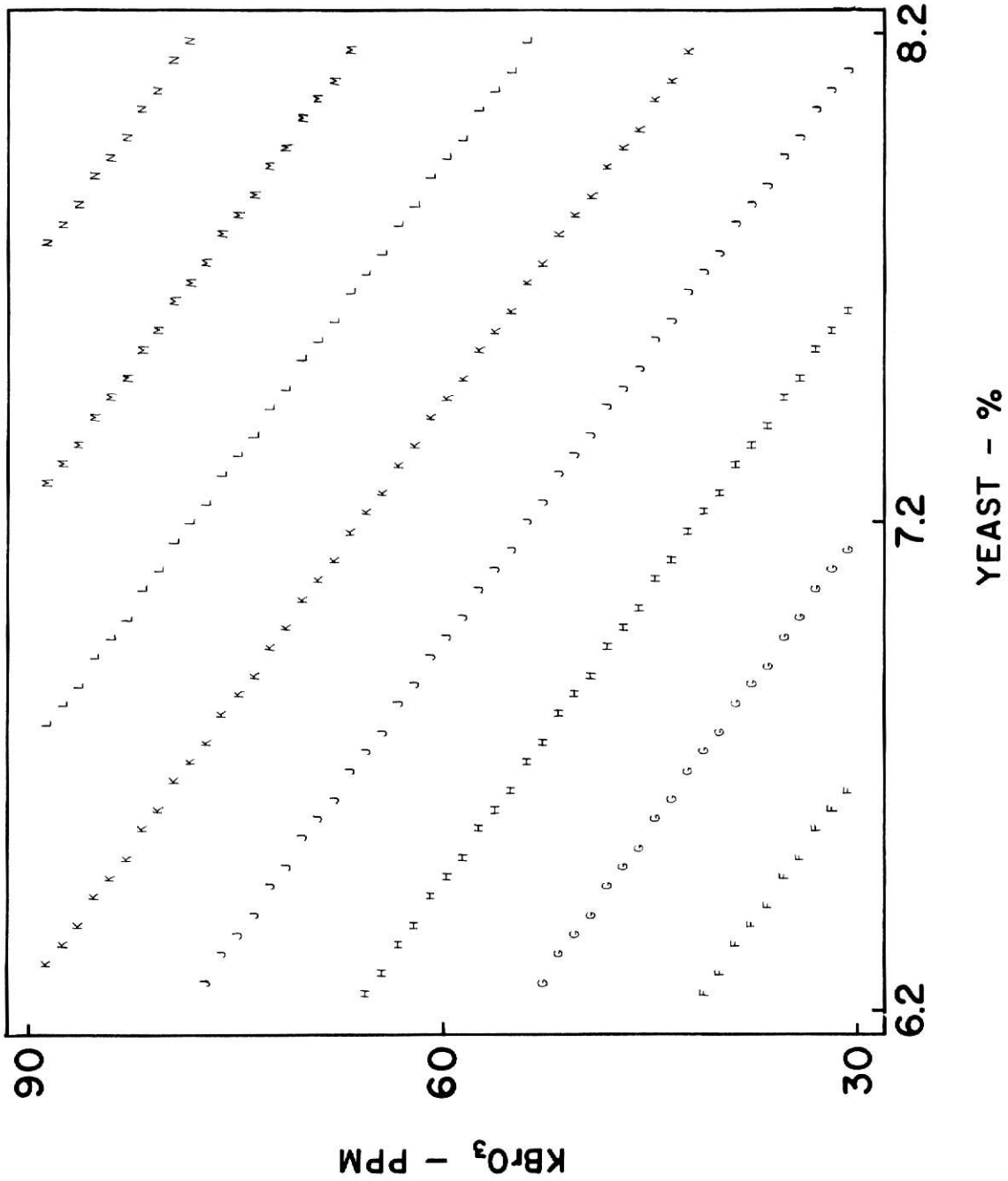
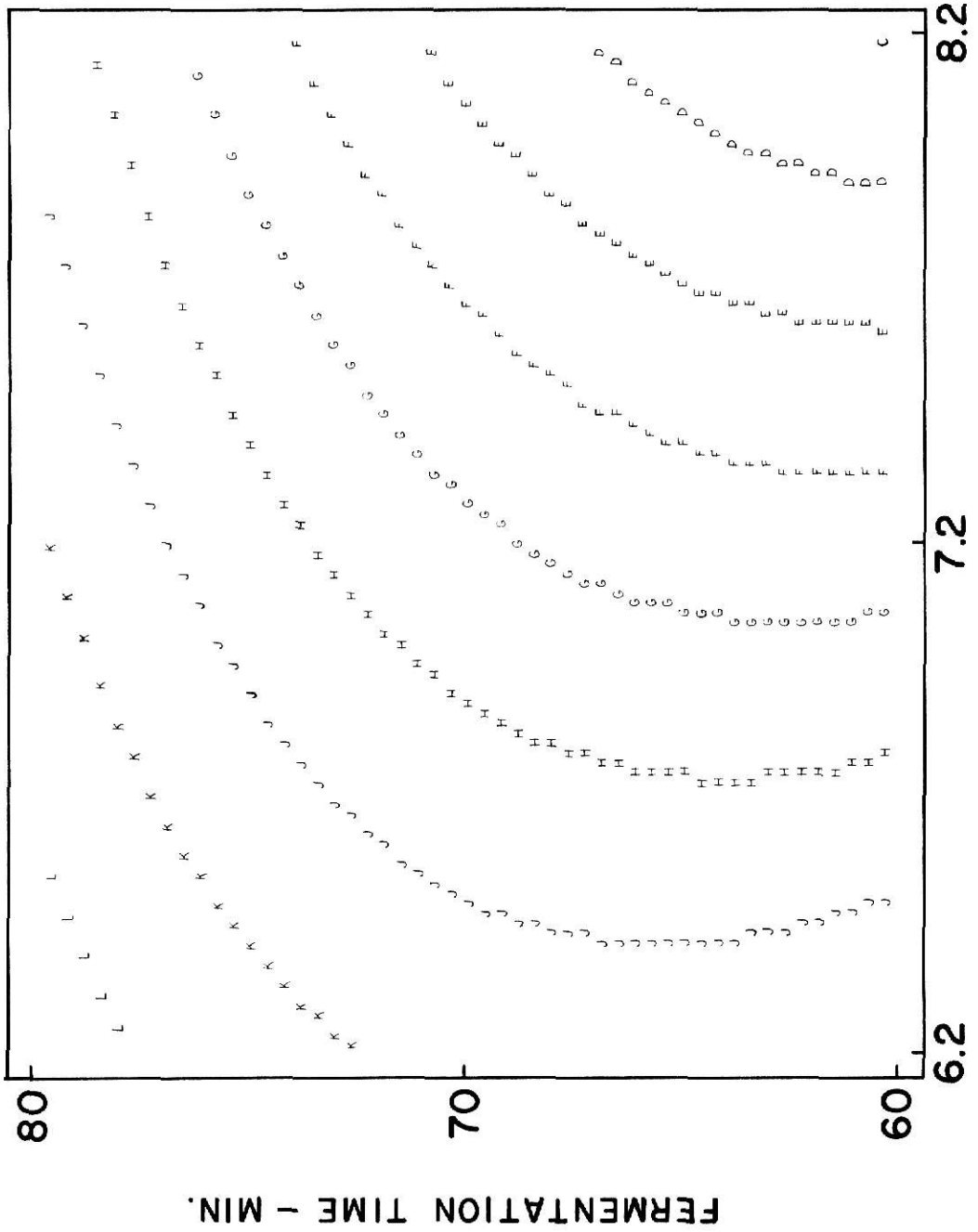

KBrO3 - PPM
90
60
30
6.2
7.2
8.2
YEAST - %

Table 5. Proof time (min.) data points for the RSM study of the effect of fermentation time, yeast concentration and $KBrO_3$ on bread characteristics.

Yeast conc.	$KBrO_3$	Fermentation times		
		60	70	80
%	ppm	min.	min.	min.
6.2	30		24	
"	60	24		25
"	90		24	
7.2	30	20		24
"	60		21.5	
"	90	20		24
8.2	30		18	
"	60	18		23
"	90		18	

Equation for response surface. $Y = 21.5 - 2.5\ x_1 + 1.75\ x_3 + 1.0\ x_3^2 + 1\ x_1x_3$ where: x_1 = yeast concentration, x_2 = fermentation time, and $x_3 = KBrO_3$. All B values included in the equation are significant at the 5% level.

Fig. 16. Contour plot of proof time (C = 17 min., D = 18 min., E = 19 min., F = 20 min., G = 21 min., H = 22 min., J = 23 min., K = 24 min., L = 25 min.) for yeast concentration and fermentation time at all levels of $KBrO_3$.


FERMENTATION TIME – MIN.
80
70
60
6.2
7.2
8.2
YEAST – %

wide variation in the effect of the oxidants used. Four RSM studies were used to investigate certain oxidants over a range of fermentation times.

Interrelationship of $KBrO_3$, KIO_3, and Fermentation Time. The effectiveness of KIO_3 used alone as an oxidant was influenced mostly by fermentation time (Table 6, Figs. 17, 18, and 19) and showed no positive interaction in combination with $KBrO_3$. As the amount of $KBrO_3$ was increased, KIO_3 must be reduced to maintain loaf volume, especially at the longer fermentation times. The best loaf volumes and loaf characteristics were obtained with high levels of $KBrO_3$ and longer fermentation times.

Interrelationship of $KBrO_3$, ADA, and Fermentation Time. With longer fermentation times, either oxidant alone produced nearly optimum bread (Table 7 and Figs. 20, 21, and 22). When used in combinations, a highly significant negative interaction resulted in no apparent improvement over either used alone.

Interrelationship of ADA, Ascorbic Acid, and Fermentation Time. Optimum levels of ascorbic acid (Table 8, Figs. 23, 24, and 25) were 150 ppm, irregardless of fermentation time. Although the figures appear to show ascorbic acid harmful at higher levels, past data does not support that trend. The optimum level of ADA was around 50 ppm at all fermentation times. However, its effectiveness was somewhat less than that of ascorbic acid. In combination, there was an additive effect with no significant interaction. The optimum combination at all fermentation times, was 150 ppm ascorbic acid and 50 ppm ADA.

Table 6. Loaf volume data points for the RSM study of the effect of $KBrO_3$, KIO_3, and fermentation time.

Fermentation Time	KIO_3	$KBrO_3$		
		0	40	80
min.	ppm	ppm	ppm	ppm
0	0		780	
"	10	810		818
"	20		818	
30	0	810		940
"	10		963 930	
"	20	900	935	900
60	0		973	
"	10	930		1025
"	20		900	

Equation for response surface. $Y = 14.1 + 6.9\ x_1 + 2.4\ x_2 - 2.8\ x_1^2 - 2.0\ x_3^2 - 2.2\ x_1x_3 - 2.2\ x_2x_3$ where: x_1 = fermentation time, x_2 = $KBrO_3$, x_3 = KIO_3. All B values included in the equation are significant at the 5% level.

Fig. 17. Contour plot of loaf volume (A = 725 cc, B = 750 cc, C = 775 cc, D = 800 cc, E = 825 cc) for $KBrO_3$ and KIO_3 at 0 fermentation time.

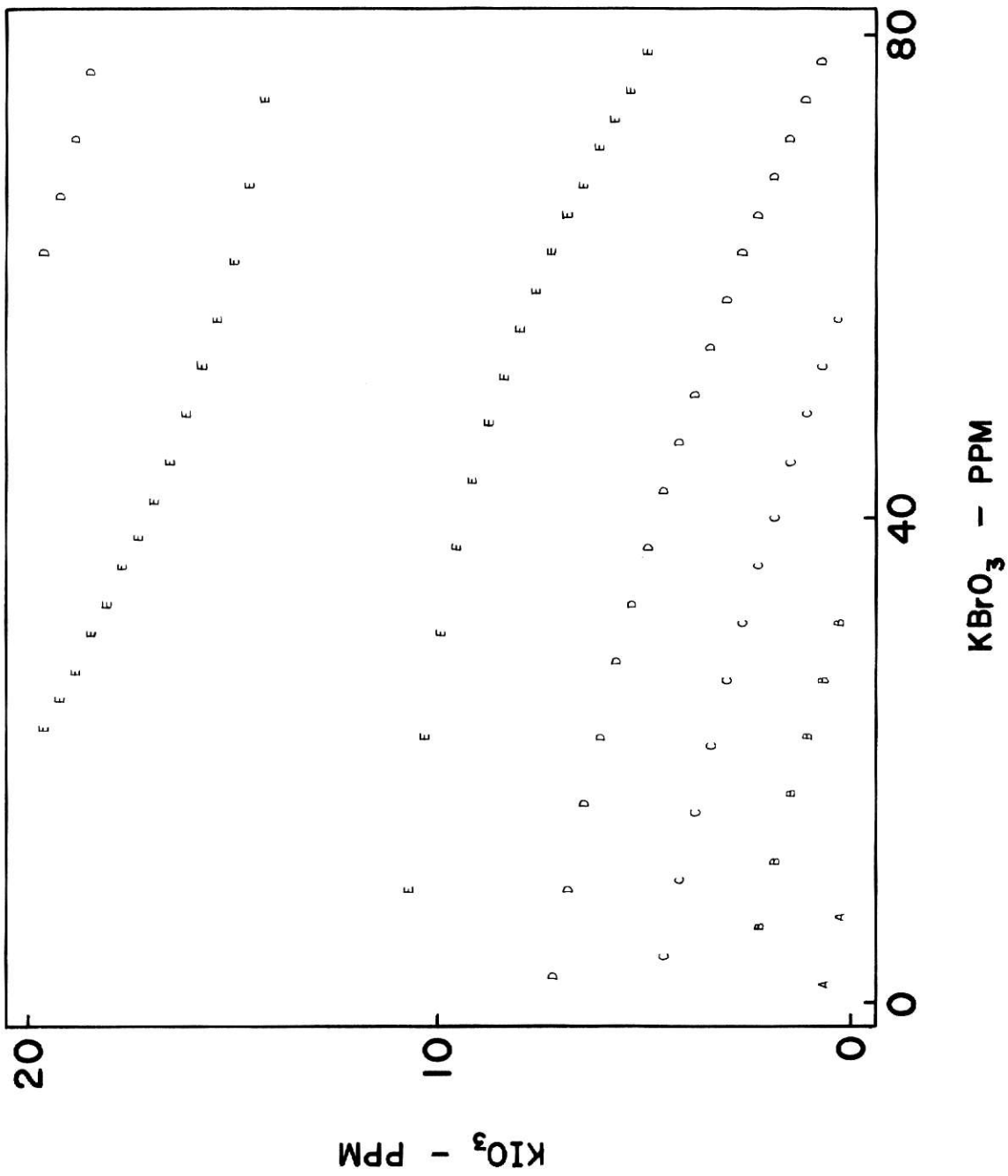

20
10
0
0
40
80
KIO3 - PPM
KBrO3 - PPM

Fig. 18. Contour plot of loaf volume (F = 850, G = 875, H = 925, K = 950) for $KBrO_3$ and KIO_3 at 30 min. fermentation time.

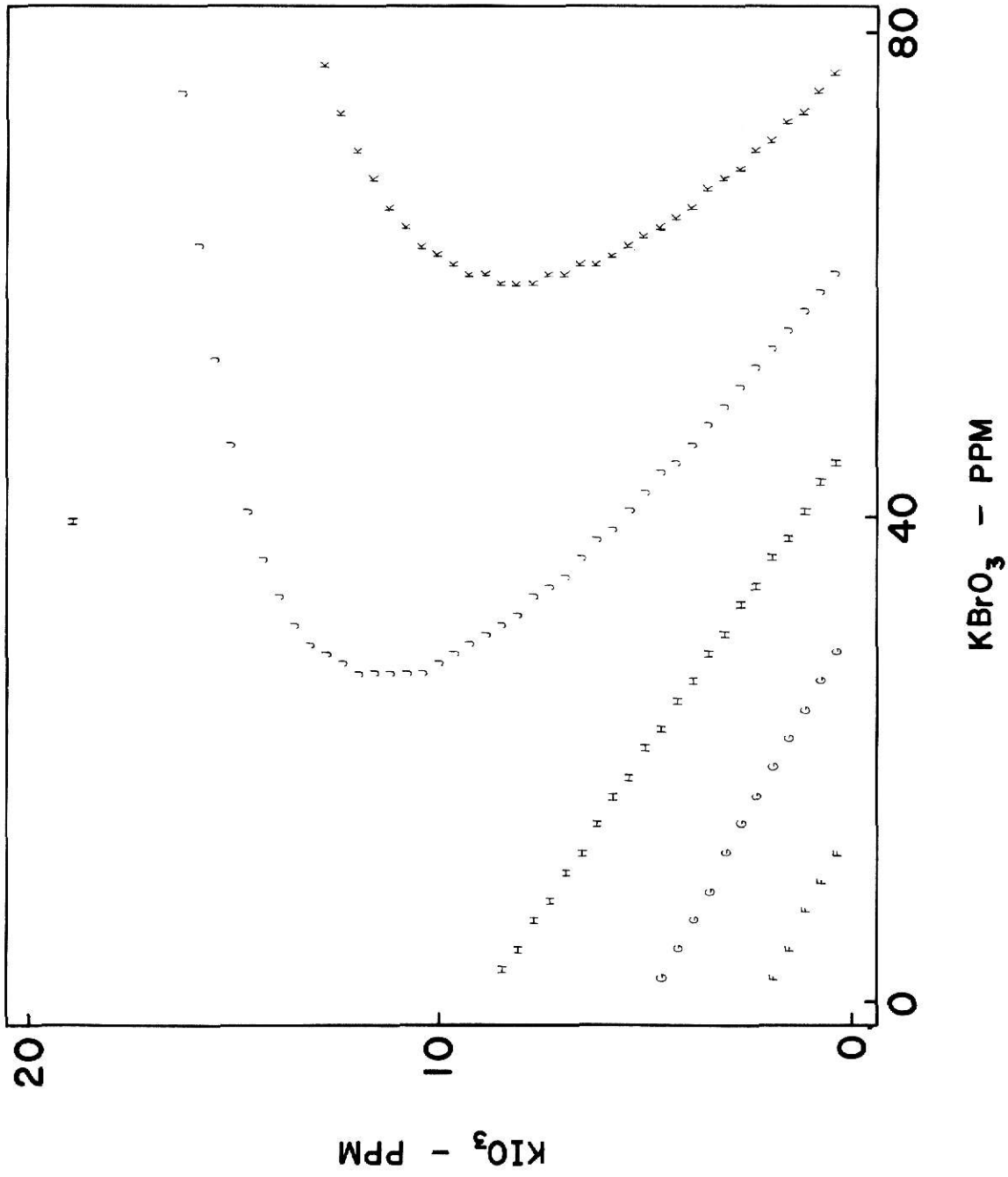

20
10
0
0
40
80
KIO3 - PPM
KBrO3 - PPM

Fig. 19. Contour plot of loaf volume (H = 900 cc, J = 925 cc, K = 950 cc, L = 975 cc, M = 1000 cc, N = 1025 cc, O = 1050 cc) for $KBrO_3$ and KIO_3 at 60 min. fermentation time.

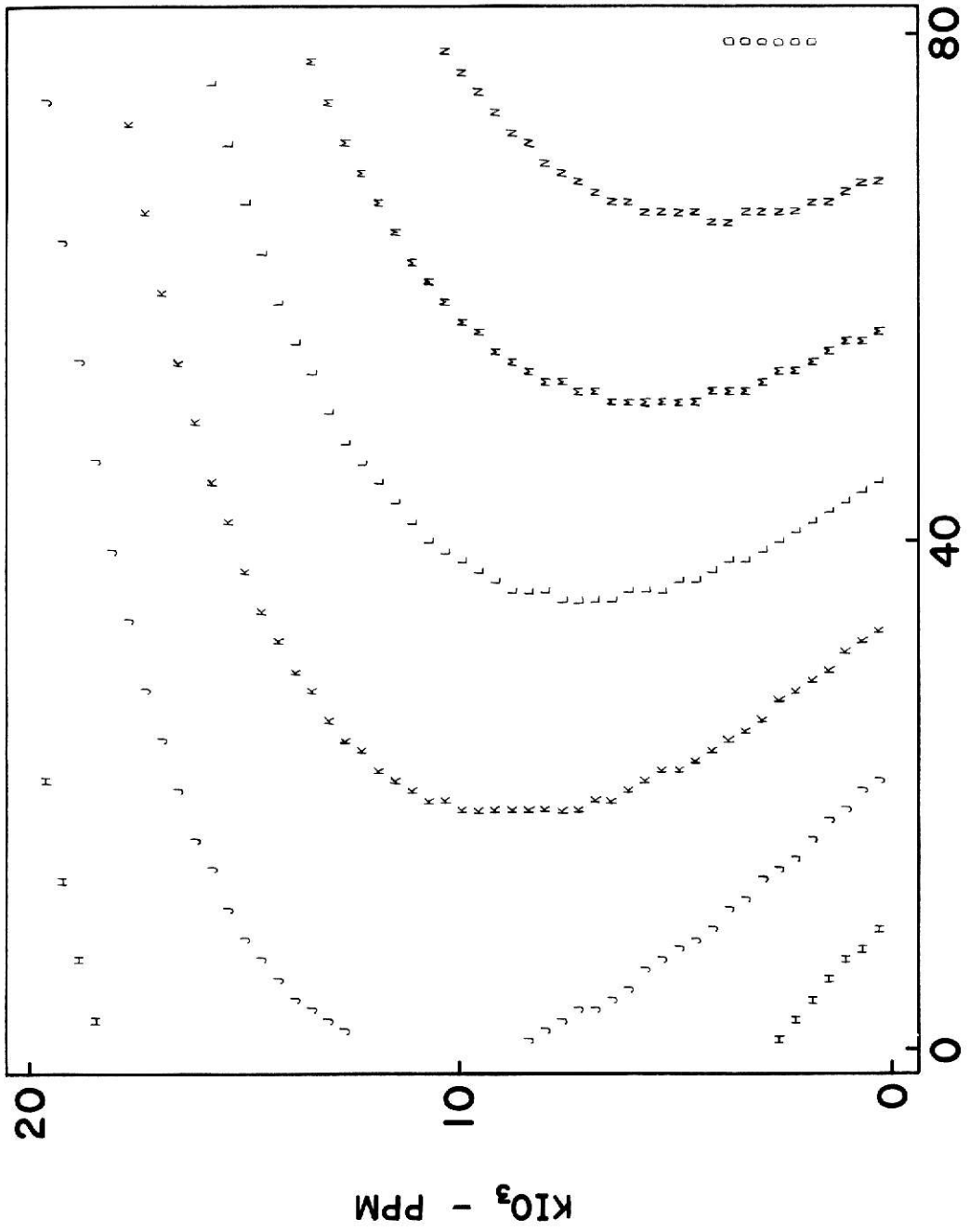

20
10
0
0
40
80
KIO3 - PPM
KBrO3 - PPM

Table 7. Loaf volume data points for the RSM study of the effect of $KBrO_3$, ADA, and fermentation time.

Fermentation time	ADA	$KBrO_3$		
		0	40	80
min.	ppm	ppm	ppm	ppm
0	0		780	
"	20	735		780
"	40		795	
30	0	810		940
"	20		945 920 937	
"	40	967		915
60	0		973	
"	20	1015		1020
"	40		977	

Equation for response surface. $Y = 945.0 + 111.9\ x_1 + 16.0\ x_2 + 18.9\ x_3 - 42.1\ x_1^2 - 15.4\ x_2^2 - 21.6\ x_3^2 - 45.5\ x_2x_3$ where: x_1 = fermentation time, $x_2 = KBrO_3$, and x_3 = ADA. All B values included in the equation are significant at the 5% level.

Fig. 20. Contour plot of loaf volume (A = 725 cc, B = 750 cc, C = 775 cc, D = 800 cc) for $KBrO_3$ and ADA at 0 min. fermentation time.

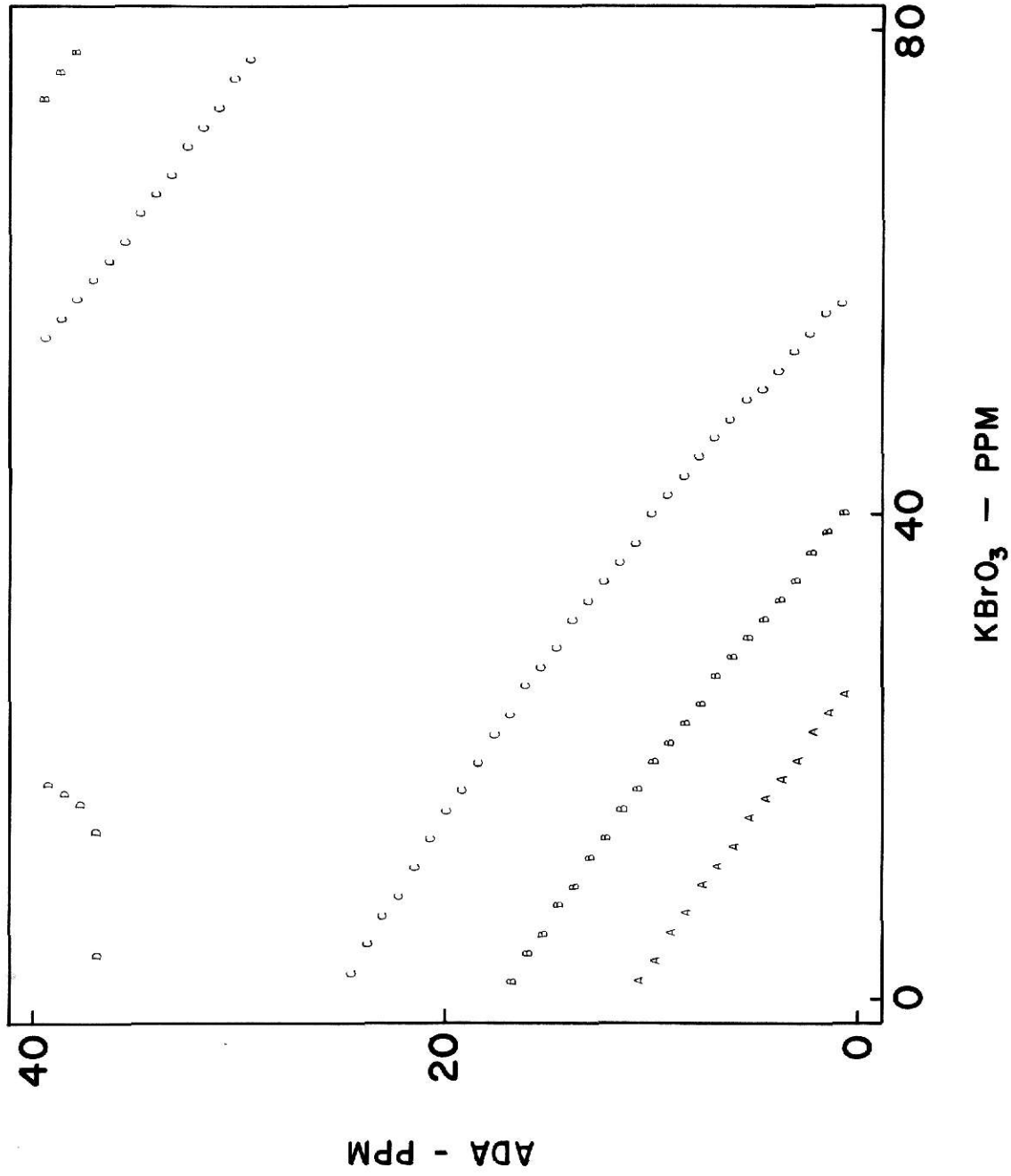

ADA - PPM
0
20
40
0
40
80
KBrO3 - PPM

Fig. 21. Contour plot of loaf volume (F = 850 cc, G = 875 cc, H = 900 cc, J = 925 cc, K = 950 cc) for $KBrO_3$ and ADA at 30 min. fermentation time.

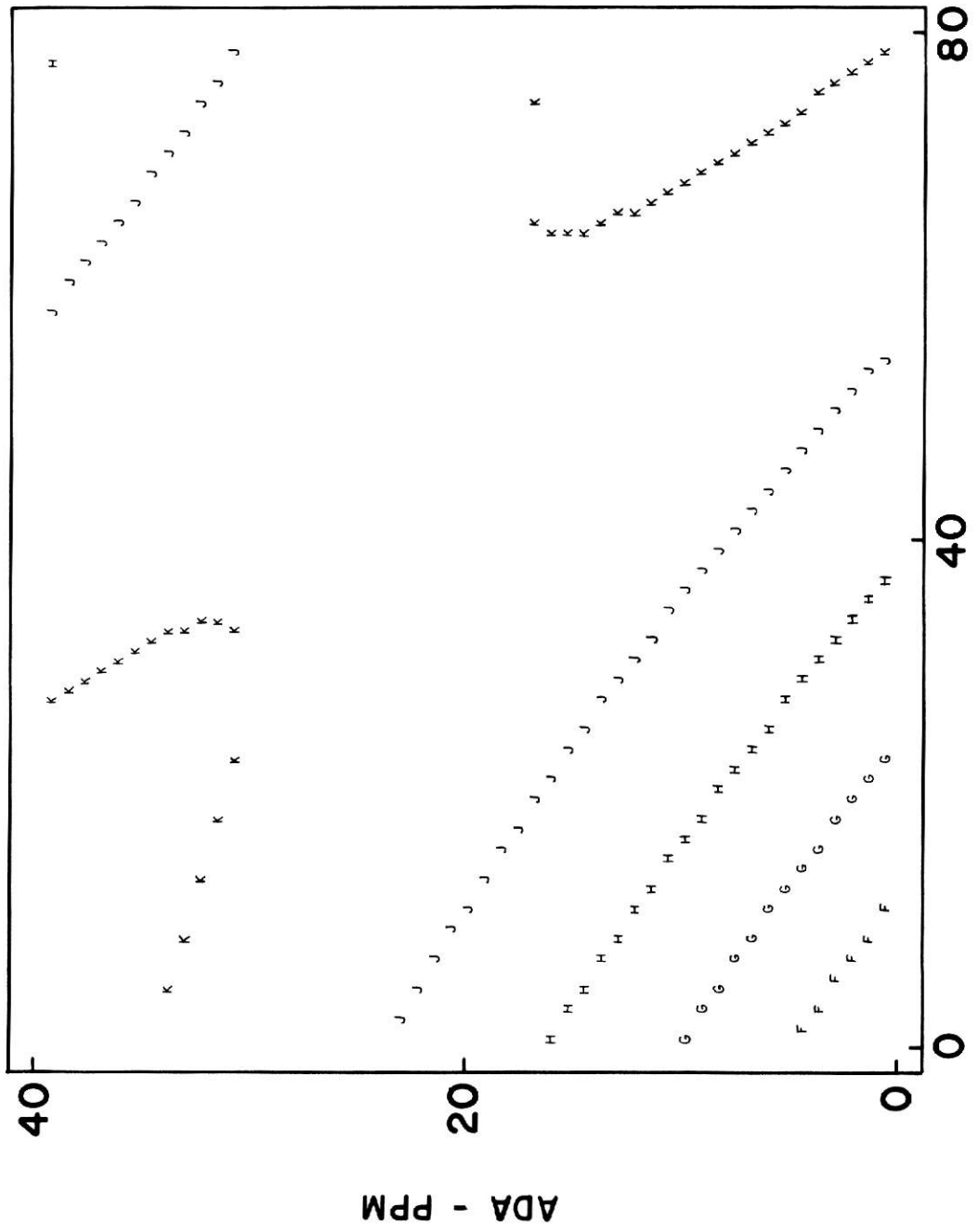

ADA - PPM
0
20
40
0
40
80
KBrO3 — PPM

Fig. 22. Contour plot of loaf volume (H = 900 cc, J = 925 cc, K = 950 cc, L = 975 cc, M = 1000 cc, N = 1025 cc) for $KBrO_3$ and ADA at 60 min. fermentation time.

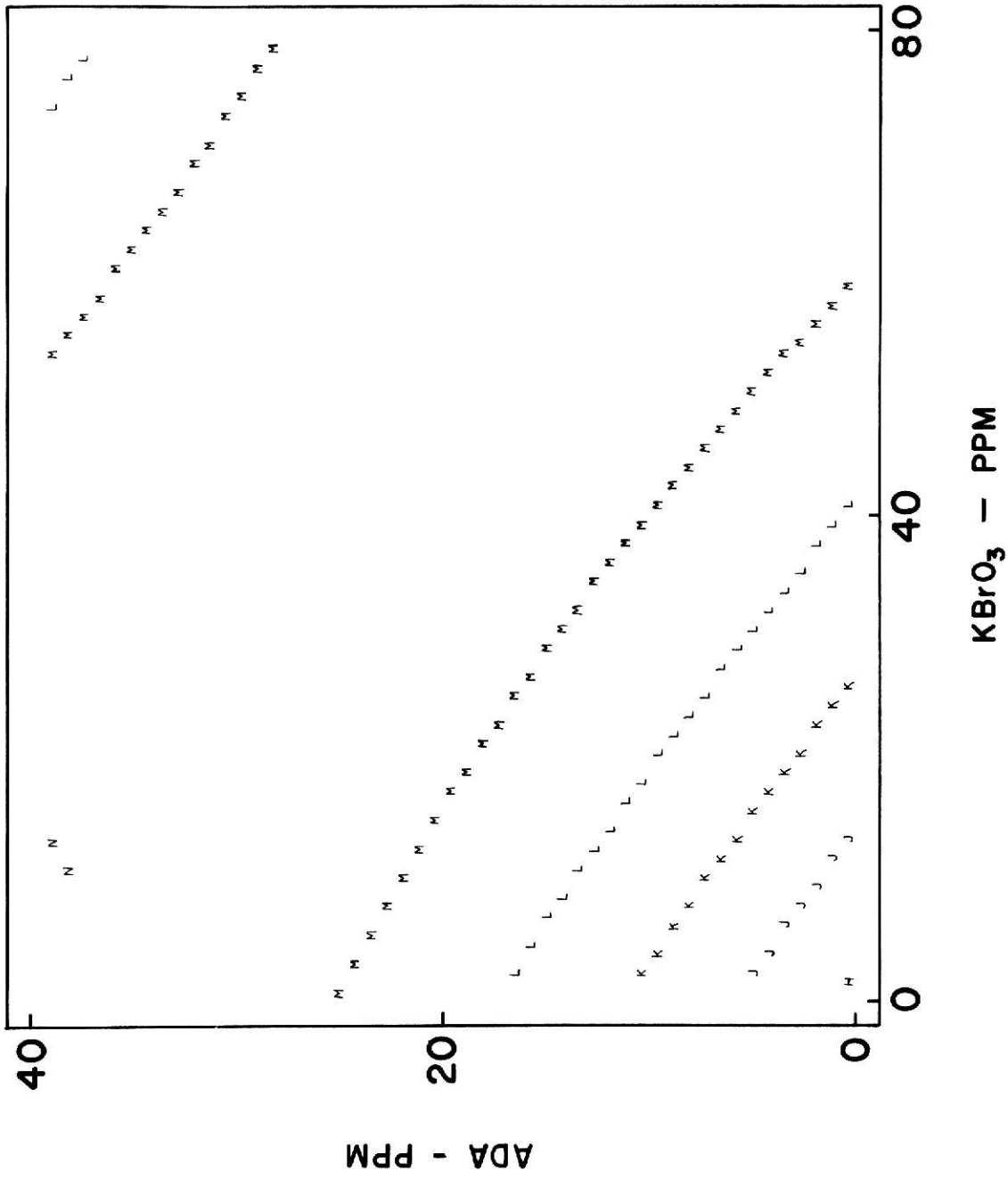

ADA - PPM
0
20
40
0
40
80
KBrO3 - PPM

Table 8. Loaf volumes data points for the RSM study of the effect of ADA, ascorbic acid, and fermentation time.

Fermentation time	Ascorbic acid	ADA		
		0	40	80
min.	ppm	ppm	ppm	ppm
0	0		808	
"	100	782		832
"	200		790	
30	0	810		860
"	100		945 950 953	
"	200	940		950
60	0		945	
"	100	965		960
"	200		965	

Equation for response surface. $Y = 949.3 + 77.9\ x_1 + 13.1\ x_2 + 27.7\ x_3 - 38.8\ x_1^2 - 25.8\ x_2^2 - 33.5\ x_3^2$ where: x_1 = fermentation time, x_2 = ADA, x_3 = ascorbic acid. All B values included in the equation are significant at the 5% level.

Fig. 23. Contour plot of loaf volume (B = 750 cc, C = 775 cc, D = 800 cc, E = 825 cc) for ADA and ascorbic acid at 0 min fermentation time.

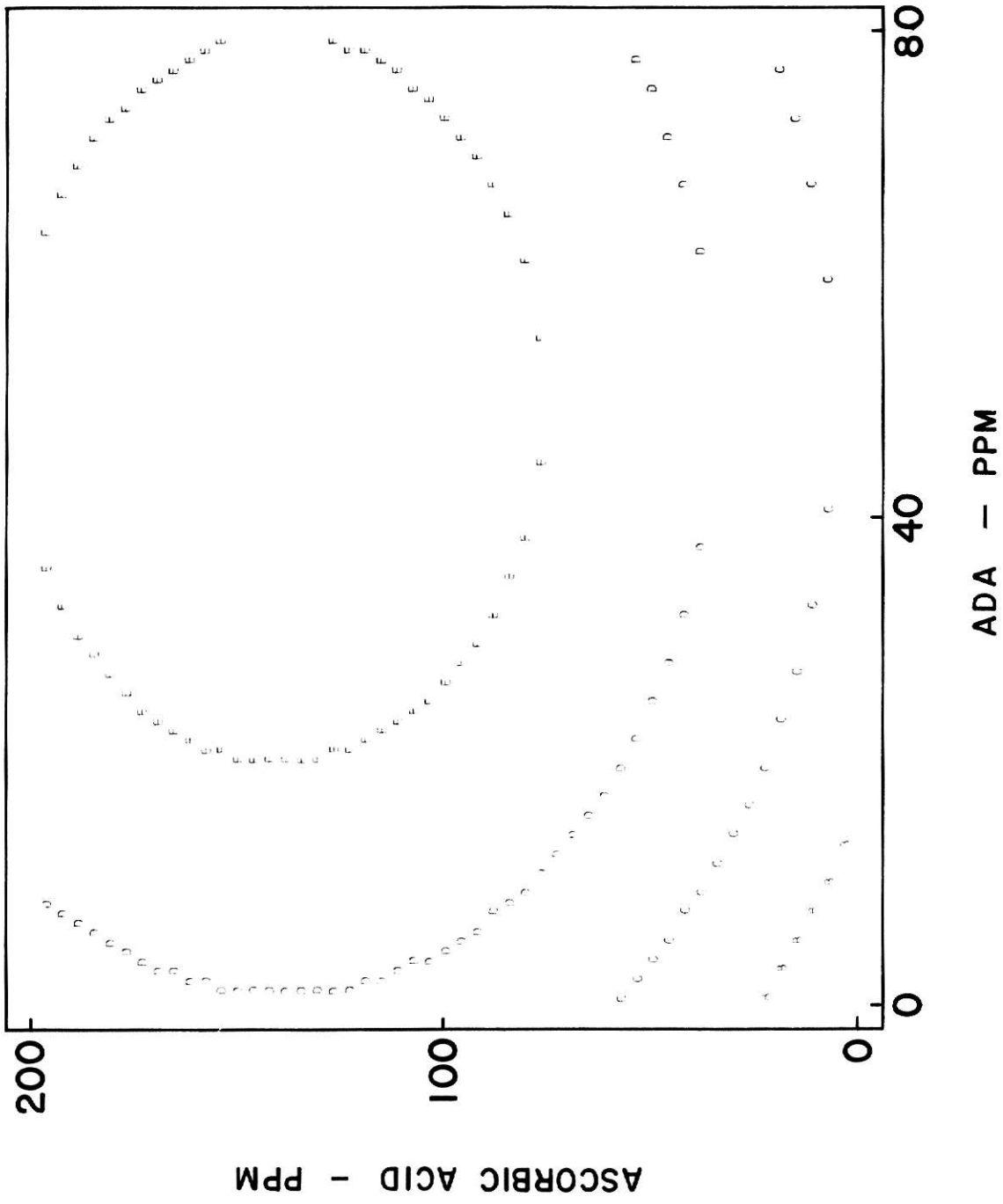

ASCORBIC ACID - PPM
200
100
0
0
40
80
ADA - PPM

Fig. 24. Contour plot of loaf volume (F = 850 cc, G = 875 cc, H = 900 cc, J = 925 cc, K = 950 cc) for ADA and ascorbic acid at 30 min. fermentation time.

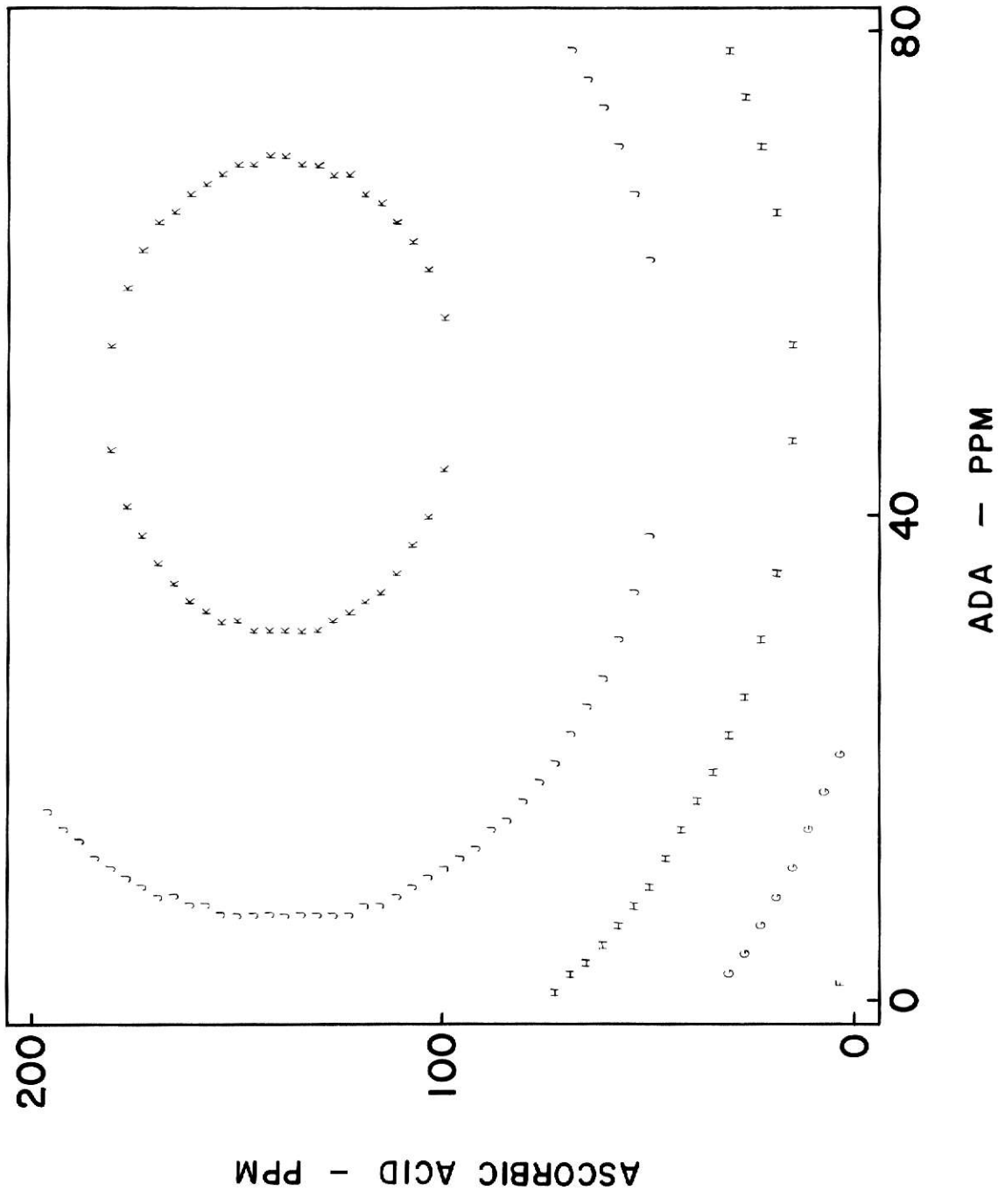
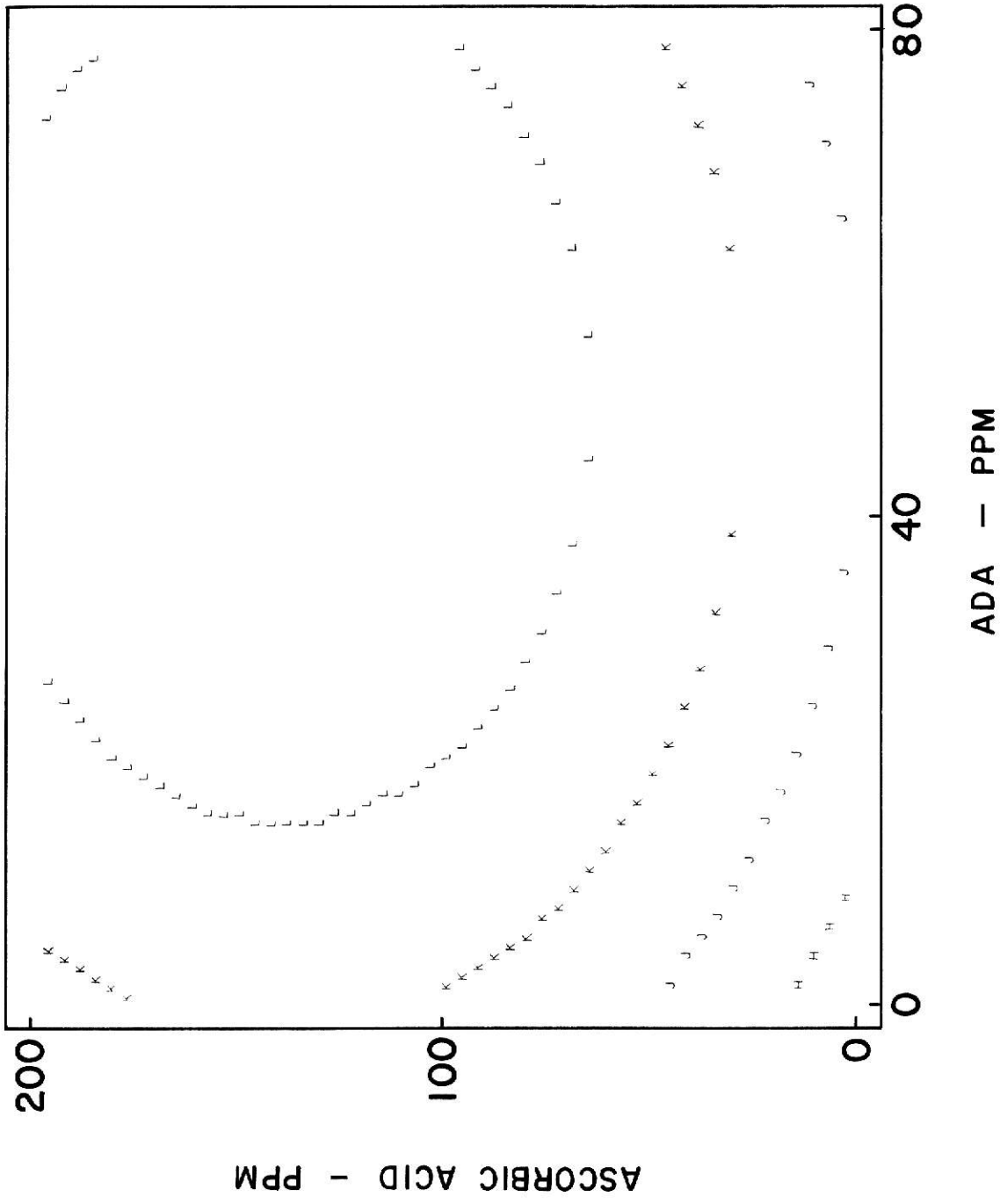

ASCORBIC ACID - PPM
200
100
0
0
40
80
ADA - PPM

Fig. 25. Contour plot of loaf volume (H = 900 cc, J = 925 cc, K = 950 cc, L = 975 cc) for ADA and ascorbic acid at 60 min. fermentation time.


ASCORBIC ACID - PPM
200
100
0
0
40
80
ADA - PPM

Interrelationship of $KBrO_3$, Ascorbic Acid, and Fermentation Time. The effect of $KBrO_3$ and ascorbic acid used alone has been discussed above. In combination (Table 9, Figs. 26, 27, 28) at all fermentation times, the two oxidants have an additive effect, and no significant interaction. Nearly optimum bread was produced using 150 ppm of ascorbic acid and 70 ppm of $KBrO_3$.

Conclusions. The two most frequently used combinations of oxidants in the baking industry $KBrO_3$:KIO_3, and $KBrO_3$:ADA appear to have no benefit when used in combination. When used separately they function as well as or better than their combination. Both $KBrO_3$:ascorbic acid and ADA:ascorbic acid exhibit additive effects on loaf volumes and crumb characteristics. The $KBrO_3$:ascorbic acid combination appears to give the highest volumes and better crumb grains at all times studied. Bread produced with that combination of oxidants was considered nearly identical to the bread produced by our standard 3-hour procedure.

Without exception, the length of fermentation time after mixing proved to be the most beneficial factor affecting bread characteristics with this short-time system. It is noteworthy that the combination of $KBrO_3$: ascorbic acid and ADA:ascorbic acid both nearly reach their optimum volume with a 30 min. fermentation time. It thus appears that ascorbic acid is particularly useful in combination with other oxidants in short-time baking systems.

Table 9. Loaf volume data points for the RSM study of the effect of $KBrO_3$, ascorbic acid, and fermentation times.

Fermentation time	Ascorbic acid	$KBrO_3$		
		0	40	80
min.	ppm	ppm	ppm	ppm
0	0		780	
"	100	782		888
"	200		850	
30	0	810		940
"	100		1015 970	
"	200	940	1015	1045
60	0		973	
"	100	965		1050
"	200		1050	

Equation for response surface. $Y = 1000 + 92.4\ x_1 + 53.4\ x_2 + 47.7\ x_3 - 49.5\ x_1^2 - 29.0\ x_2^2 - 37.2\ x_3^2$ where: x_1 = fermentation time, x_2 = $KBrO_3$, x_3 = ascorbic acid. All B values included in the equation are significant at the 5% level.

Fig. 26. Contour plot of loaf volume (A = 725 cc, B = 750 cc, C = 775 cc, D = 800 cc, E = 825 cc, F = 850 cc, G = 875 cc) for $KBrO_3$ and ascorbic acid at 0 min. fermentation time.

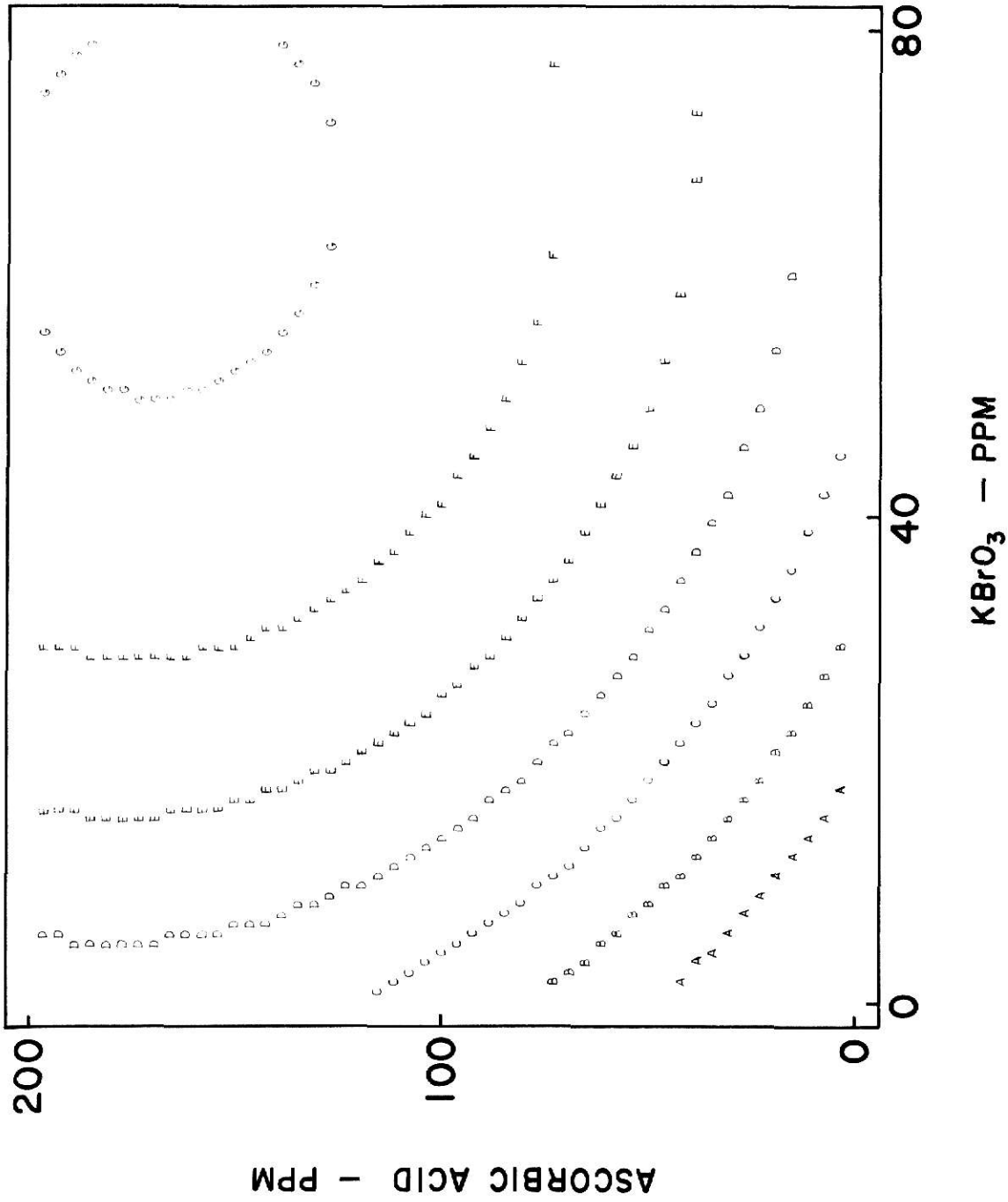

ASCORBIC ACID – PPM
200
100
0
0
40
80
$KBrO_3$ – PPM

Fig. 27. Contour plot of loaf volume (F = 850 cc, G = 875 cc, H = 900 cc, J = 925 cc, K = 950 cc, L = 975 cc, M = 1000 cc, N = 1025 cc) for $KBrO_3$ and ascorbic acid at 30 min. fermentation time.

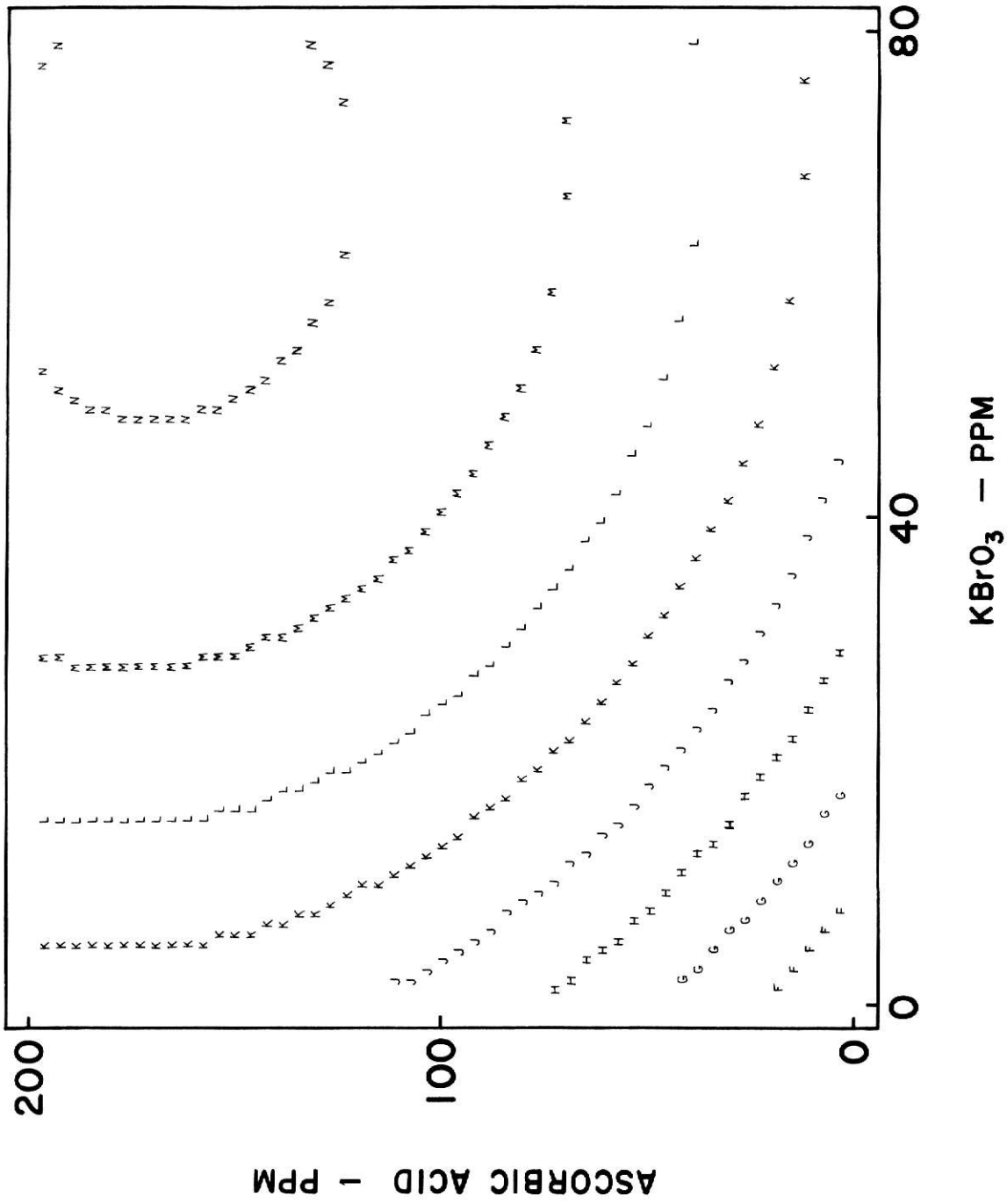
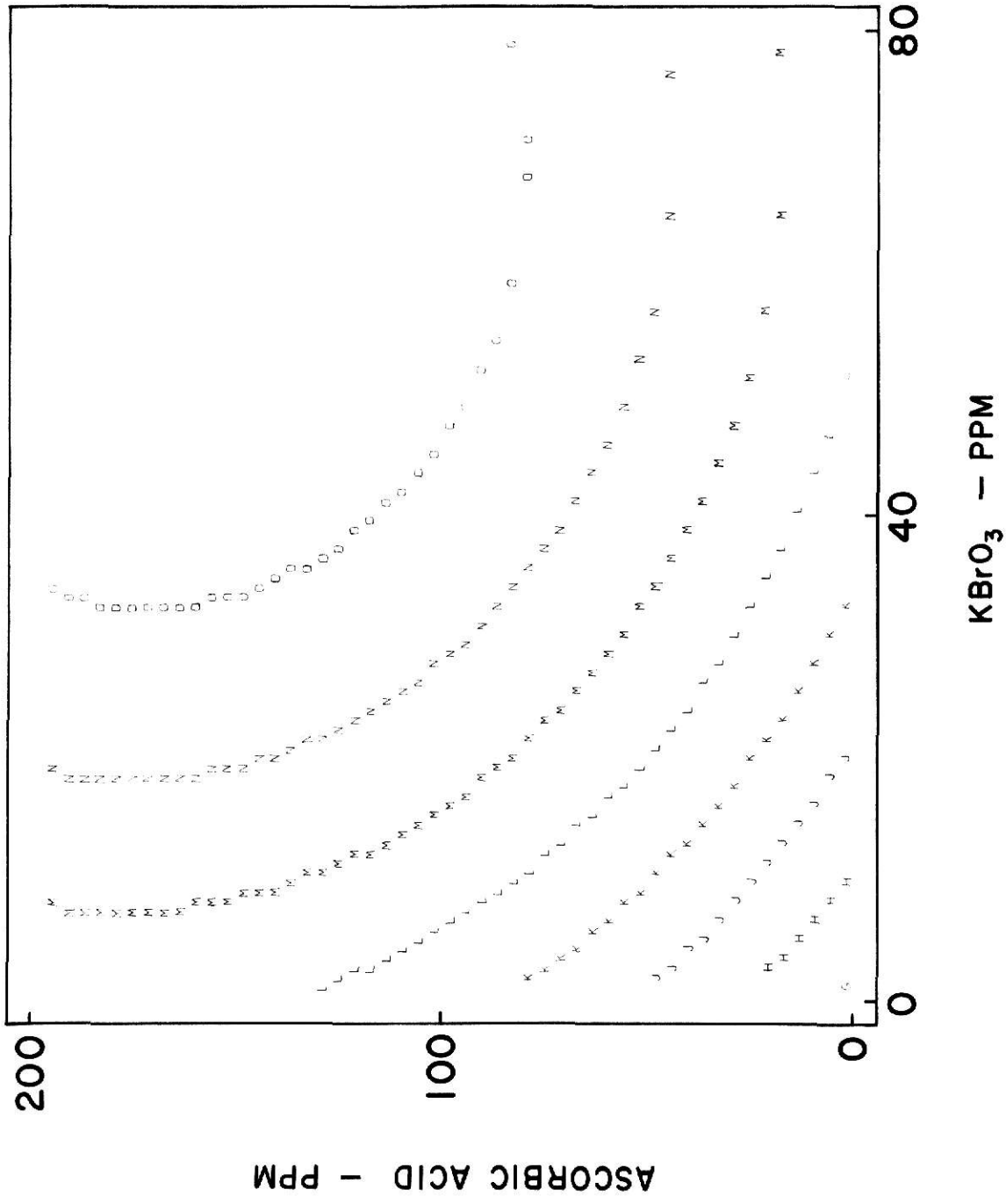

ASCORBIC ACID – PPM
200
100
0
0
40
80
KBrO3 – PPM

Fig. 28. Contour plot of loaf volume (G = 875 cc, H = 900 cc, J = 925 cc, K = 950 cc, L = 975 cc, M = 1000 cc, N = 1025 cc, O = 1050 cc) for $KBrO_3$ and ascorbic acid at 60 min. fermentation time.


ASCORBIC ACID – PPM
200
100
0
0
40
80
$KBrO_3$ – PPM

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