A Response-Surface Analysis of the Oxidative Requirements of No-Time Doughs

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ABSTRACT

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The effects of three commercially available oxidants on specific internal and external quality characteristics of no-time doughs were examined by response-surface methodology. The oxidant system included azodicarbonamide, ascorbic acid, and potassium bromate. In general, the quality of the loaves improved when ascorbic acid was excluded from the system. However, the addition of ascorbic acid tended to affect the levels of azodicarbonamide and potassium bromate required to obtain the maximum quality response. There was a definite interaction among the three oxidants that varied depending on the quality characteristics.

Accelerated dough system, quick dough processing, chemical dough development, and no-time dough are all descriptive terms for a straight-dough method to produce bread without bulk fermentation. This method has many advantages over the sponge-dough methods (Olsen 1974, Shirley 1977, Kamman 1979).

The no-time dough process requires several formulation adjustments to produce bread comparable in quality to sponge-dough bread. These include increases in the yeast level (Alesch 1971, Bingaman 1972, Kamman 1979, Smerak 1983) and dough temperature (Marston 1966, Bingaman 1972, Kamman 1979), and dough water absorption (Alesch 1971, Bingaman 1972, and Smerak 1983), as well as addition of yeast nutrients (Kamman 1979). The most important modification required is the addition of oxidants in the appropriate amounts and combination (Marston 1966, Alesch 1971, Bingaman 1972, Kamman 1979, Smerak 1983).

In this study, the oxidants ascorbic acid, potassium bromate, and azodicarbonamide (ADA) were used in combination at varying levels, according to a statistical design, in order to determine the optimum levels for use in no-time doughs.

MATERIALS AND METHODS

Formulation

Breads by the no-time method in this study were prepared according to the formula in Table I. The effect of the oxidants was determined for two different commercial bread flours. Flour A (11.4% protein and 0.47% ash, 14% mb) was approximately one year old and had been held in refrigerated storage (4°C) until about one week before it was needed, then allowed to equilibrate at room temperature before use. Flour B (11.3% protein and 0.49% ash, 14% mb) was freshly milled and stored at room temperature.

Sucrose and nonfat milk solids were each used at 6% (based on flour weight = 100%), in order to improve the flavor of the bread. Ammonium sulfate was used as the yeast nutrient. The three commercially available oxidants evaluated in this study were potassium bromate, ascorbic acid, and ADA. The instant yeast used was hydrated in 80–90° F (27–32° C) water for approximately 5 min before mixing. The loaves were weighed and measured for volume by rapeseed displacement 1 hr after baking, before they were individually wrapped in polyethylene bread bags.

Loaf Characteristics

The bread was scored one day after baking for external and internal loaf characteristics. During the subjective scoring procedure, numerical values were assigned to various quality characteristics. The external characteristics scored were loaf volume, crust color, loaf symmetry, and crust break and shred. The internal characteristics scored were grain, crumb texture, crumb color, aroma, taste, and mouthfeel. The sum of all these scores represents the total quality score for the bread.

Other characteristics were also calculated in this study. The BS×V index is the product of the crust break and shred score times the specific volume. The compression force value (CFV) was determined on three-day-old bread with the Instron universal testing machine (model 1000) according to AACC method 74-09 (AACC 1983). The force index is a ratio of the CFV and the specific loaf volume and is an indicator of the loaf firmness (i.e., the larger the index, the firmer the crumb per cubic centimeter of bread). The time required for the doughs to proof to the standard height (proof time) and the average loaf specific volume were also recorded.

Statistical Design

The combinations of oxidant levels were based on a rotatable central composite design (Table II). This design was evaluated with flour A, and the 20 combinations were baked in random order. The resulting scores and indices were analyzed using response-surface methodology (RSM). The resulting RSM-predicted responses were verified with both flours A and B. The reported scores and indices are the results of at least duplicate bakes on separate days.

RESULTS AND DISCUSSION

Response-Suface Analysis

A second-order response-surface prediction was fitted for each characteristic using the Statistical Analysis System RSREG procedure (SAS 1982). Predicted optimum responses for each characteristic were defined by specified amounts of the three oxidants. Both the predicted responses at optimum and the

TABLE I

No-Time Dough Formula[a]

Ingredients	Amount (%)[b]
Flour (hard red winter)	100
Sucrose	6
Nonfat milk solids	6
Salt	2
Ammonium sulfate	0.06
Oxidation[c]	Variable
Shortening[d]	3
Yeast	
compressed	4.5
or instant (hydrated)	1.5
Water[e]	Variable

[a] Bread was baked by the following procedure. Mix dough to optimum development. Dough temperature 84 ± 2° F (29 ± 1° C). Divide dough immediately into 562 g pieces; round and let rest 10 min. Mold, pan, and proof to height of 100 mm from bottom of pan. Bake for 17 min at 450° F (232° C).

[b] Based on flour weight = 100%.

[c] Oxidation includes potassium bromate, ascorbic acid, and azodicarbonamide at various levels.

[d] Shortening contains mono- and diglycerides as emulsifiers.

[e] Flour A = 68% absorption; flour B = 66% absorption.

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combination of oxidants needed to achieve that response are given in Table III.

The RSM analysis also showed that the oxidation system did influence specific characteristics of no-time doughs. At the 10% significance level ($P \leq 0.10$), ADA was shown to significantly affect the total score, mouthfeel score, and proof time characteristics. Of the three oxidants, ascorbic acid significantly affected the break and shred score, BS×V, and the force index. Potassium bromate plus ADA were the significant factors affecting the internal score, whereas the grain score was significantly affected by potassium bromate plus ascorbic acid. Although the oxidants changed the loaf specific volume and external score, these effects were not statistically significant.

Except for the grain score and mouthfeel score, the combinations of oxidants required to obtain each characteristic's predicted values included some of each of the three oxidants at various levels (Table III). The grain score did not require the presence of ADA to achieve the optimum response, and potassium bromate was not needed in the levels of oxidants for the optimum mouthfeel score response.

To verify each characteristic's response-surface predictions, bread was baked from doughs using each of the 10 optimum

TABLE II

Central Composite Design of Oxidation Levels for No-Time Doughs

	Oxidants (ppm)		
Evaluation[a]	Potassium Bromate	Ascorbic Acid	ADA[b]
1	15	24	9
2	15	24	36
3	60	24	9
4	60	24	36
5	15	96	9
6	15	96	36
7	60	96	9
8	60	96	36
9	38	60	0
10	38	60	45
11	0	60	22
12	75	60	22
13	38	0	22
14	38	120	22
15–20	38	60	22

[a] Evaluations 1–14 were randomly tested with replicate evaluations 15–20 interspersed at regular intervals.

[b] Azodicarbonamide.

TABLE III

Response-Surface Analysis

	Levels of Oxidants (ppm) for Optimum Response					
Characteristic	Potassium Bromate	Ascorbic Acid	ADA[a]	Predicted Value at Optimum	Significant Factors[b]	R^2
Total score	39.9	65.6	23.4	84.2	ADA	0.48
External score	78.7	55.0	22.9	24.9	None	0.40
Internal score	34.2	54.1	26.2	59.4	Potassium bromate, ADA	0.75
Break and shred score	60.5	76.9	20.8	3.9	Ascorbic acid	0.58
Grain score	38.9	16.2	0.0	8.1	Potassium bromate, Ascorbic acid	0.54
Mouthfeel score	0.0	81.7	35.7	7.89	ADA	0.68
Specific volume	51.4	56.3	25.9	5.52	None	0.41
BS×V index[c]	52.3	64.1	19.3	21.6	Ascorbic acid	0.43
Force index[d]	48.2	52.3	32.7	46.0	Ascorbic acid	0.52
Proof time[e]	46.5	58.2	30.7	58.8	ADA	0.65

[a] ADA = Azodicarbonamide.

[b] Significant at the 10% confidence level ($P \leq 0.10$).

[c] Break and shred score multiplied by the loaf specific volume.

[d] Mean compression firmness value (g) divided by the mean loaf specific volume (cm^3/g).

[e] The time it takes for the dough to reach a height of 100 ± 2 mm from the bottom of the pan.

TABLE IV

Results of Bake Tests Based on Response Surface Predictions

	Response-Surface Methodology Solution (ppm)[a]					Flour A[b]		Flour B[b]	
Characteristic	Potassium Bromate	Ascorbic Acid	ADA	Predicted Value	Maximum Value	Mean	SD	Mean	SD
Total score	39.9	65.6	23.4	84.2	100	83.69	0.43	84.17	0.63
External score	78.7	55.0	22.9	24.9	30	25.13	0.18	24.88	0.13
Internal score	34.2	54.1	26.2	59.4	70	58.88	0.53	59.00	0.25
Break and shred score	60.5	76.9	20.8	3.9	5	4.13	0.18	3.63	0.13
Grain score	38.9	16.2	0.0	8.1	10	8.00	0.00	8.13	0.18
Mouthfeel score	0.0	81.7	35.7	7.98	10	7.75	0.35	8.13	0.18
Specific volume	51.4	56.3	25.9	5.52	None	5.63	0.08	5.80	0.17
BS×V index[c]	52.3	64.1	19.3	21.6	None	20.25	0.96	19.01	0.59
Force index[d]	48.2	52.3	32.7	46.0	None	45.85	2.82	49.10	1.35
Proof time[e]	46.5	58.2	30.7	58.8	None	59.00	2.83	59.50	6.36

[a] Levels of oxidants needed for optimum response. ADA = Azodicarbonamide.

[b] Based on at least duplicate bakes on separate days.

[c] Break and shred score multiplied by the loaf specific volume.

[d] Mean compression firmness value (g) divided by the mean loaf specific volume (cm^3/g).

[e] The time it takes for the dough to reach a height of 100 ± 2 mm from the bottom of the pan.

oxidant combinations and with flours A and B. The mean scores from these bake tests are given in Table IV.

All of the individual scores and indices for flours A and B were similar to their predicted values. The specific volumes of the loaves from both flours exceeded the predicted response. The BS×V indices of both flours were less than the predicted response, indicating a lower exterior quality. The texture of breads made from flour B was firmer than from flour A and gave a larger force index than the predicted value for both flours. Overall, the similarity between actual and predicted values indicated that the statistical model was useful and that it could be used with different flours having similar protein levels.

Results from Optimum Oxidant Combinations

The statistical model provided 10 optimum solutions, one for each quality characteristic, which could be used to achieve 10 specific optimum responses in no-time doughs. Because it was impossible to use all 10 RSM solutions, one combination of oxidants needed to be found that would give nearly optimum response for each characteristic. Doughs were prepared from flours A and B for each of the 10 optimum oxidant combinations. The resulting baked loaves were evaluated for each of the quality characacteristics and the scores were averaged.

Within each of the quality characteristics, the actual values and the predicted responses were very similar. However, because all scores were summed for the total score, the most representative combination of oxidants chosen was that for the total score of the characteristics. This combination was composed of 39 ppm potassium bromate, 23 ppm ADA, and 66 ppm ascorbic acid.

Selection Criterion for the Maximum Response

Because the optimum responses provided by the RSREG procedure in SAS may be maximum, minimum, or saddle points, a second approach was used to assure that the area of maximum response for the more important characteristics would be found. The entire grid of predicted responses was searched for all combinations of the three oxidants, and those that met specific selection criteria were chosen for further pursual. The selection criteria used were the following: total score ≥ 85, grain score ≥ 7.9, specific volume ≥ 5.6, force index ≤ 45. There were 104 combinations of the three oxidants that produced predicted responses meeting these selection criteria. The 104 combinations were sorted, and every fifth combination is presented in Table V.

Interestingly, the combinations of oxidants that produced results meeting the selection criteria were those including little or no ascorbic acid (Table V). The recommended levels of potassium bromate and ADA varied relatively little and approximate those for the optimum response for total score.

Contour Plots

The requirement for ascorbic acid in the oxidation system was investigated further with contour plots that show the predicted responses for a specified quality characteristic due to varying levels of two oxidants, while the third is held at a constant level. As the contour shading of the plot surface gradates from light to dark (less dense to very dense), the predicted values increase. The contour plots for the quality characteristics total score, mouthfeel score, and proof time are given in Figure 1. These plots compare the effects of potassium bromate and ADA while the ascorbic acid level was held constant at either 66 ppm (plots A) or 0 ppm (plots B). The 66 ppm level was selected because this was the level used in the RSM solution for total score (Table IV).

The plots in Figure 1 illustrate the significant effect that ADA has on the total score, showing more change in the surface contour along the ADA axis than along the potassium bromate axis. Also, the values for the maximum total score response were slightly higher when ascorbic acid was left out (plot B) than when it was added (plot A). When 66 ppm of ascorbic acid was included in the oxidation system, the total score maximum range was 83.95–84.23. However, when ascorbic acid was removed from the oxidation system (plot B), the total score maximum range increased to 84.90–85.28.

These plots also show the interactions of the three oxidants on the levels needed to give the maximum response. The total score plot A required the combination of 16–62 ppm potassium bromate, 14–34 ppm ADA, and 66 ppm ascorbic acid to obtain the

TABLE V

Oxidation Levels Meeting Characteristic Criteria of a Total Score ≥ 85, a Grain Score ≥ 7.9, a Specific Volume ≥ 5.6, and a Force Index ≤ 45[a]

Characteristics[b]										Oxidants (ppm)		
Total Score	**Grain Score**	**Specific Volume**	**Force Index**	**Break and Shred Score**	**Mouthfeel Score**	**Interior Score**	**Exterior Score**	**Proof Time**	**BS×V[c] Index**	**Potassium Bromate**	**Ascorbic Acid**	**ADA[d]**
85.0	7.9	5.6	44.8	3.9	8.1	25.6	59.5	58.5	22.2	54	6	36
85.0	8.0	5.6	43.6	4.0	8.0	25.6	59.5	58.9	22.4	45	9	30
85.0	7.9	5.7	44.3	3.9	8.1	25.6	59.5	58.4	22.1	51	6	36
85.0	7.9	5.6	44.7	4.0	8.1	25.6	59.5	58.8	22.5	54	6	34
85.0	7.9	5.6	44.6	4.1	8.0	25.6	59.5	59.6	22.9	54	6	30
85.0	8.0	5.6	44.6	4.0	8.1	25.6	59.5	59.2	23.3	54	6	32
85.1	8.0	5.6	43.0	4.1	7.9	25.7	59.5	60.5	23.3	45	3	24
85.1	8.0	5.6	43.7	4.1	8.0	25.7	59.5	59.6	22.9	48	6	28
85.1	7.9	5.7	43.8	3.9	8.1	25.6	59.5	58.5	22.3	48	6	34
85.1	8.0	5.6	43.8	4.1	7.9	25.7	59.5	60.4	23.3	51	3	26
85.1	8.0	5.6	44.9	4.1	8.0	25.7	59.5	59.9	23.1	57	3	30
85.1	8.0	5.6	43.6	4.2	7.9	25.7	59.5	61.1	23.6	51	0	24
85.1	7.9	5.7	41.4	4.1	7.9	25.8	59.5	59.8	23.3	36	0	24
85.1	7.9	5.7	41.8	4.1	7.9	25.8	59.5	60.1	23.3	39	0	24
85.1	8.0	5.7	43.4	4.1	8.0	25.7	59.5	59.6	23.0	48	3	28
85.2	7.9	5.7	42.5	4.0	8.0	25.7	59.5	59.2	22.9	42	3	28
85.2	7.9	5.7	43.4	4.0	8.1	25.7	59.6	58.8	22.7	48	3	32
85.2	8.0	5.6	44.6	4.1	8.0	25.8	59.5	59.9	23.3	57	0	30
85.2	7.9	5.7	42.1	4.1	8.0	25.8	59.5	59.7	23.2	42	0	26
85.2	7.9	5.7	44.1	4.1	8.1	25.8	59.5	59.2	23.0	54	0	32
85.3	7.9	5.7	43.6	4.0	8.1	25.8	59.6	59.0	22.9	51	0	32
85.3	7.9	5.7	43.1	4.0	8.1	25.8	59.6	58.8	22.9	48	0	32

[a] Only the criteria for total score, grain score, specific volume, and force index were used in selecting these combinations of oxidants.

[b] The values are ranked, low to high, according to the total score, grain score, specific volume, and force index.

[c] Break and shred score multiplied by the loaf specific volume.

[d] ADA = Azodicarbonamide.

maximum reponse. For plot B, the area of maximum response was defined by the levels of 16–72 ppm potassium bromate, 20–46 ppm ADA, and 0 ppm ascorbic acid. When the ascorbic acid was excluded from the oxidation system, not only did the maximum response increase in value, but the bread became also more tolerant to higher levels of potassium bromate and ADA.

Although the contour plots for the external and internal scores are not shown here, the trends for the total score held true for its two components. When ascorbic acid was omitted from the oxidation system, the ranges of maximum scores increased from 24.78–24.98 to 25.62–25.85 for the external score and from 59.27–59.44 to 59.42–59.57 for the internal score. The amounts of potassium bromate and ADA needed or tolerated for these maximum responses were also affected by the presence of ascorbic acid. For the external score, 34–72 ppm potassium bromate and 10–34 ppm ADA with 66 ppm ascorbic acid were optimal to obtain

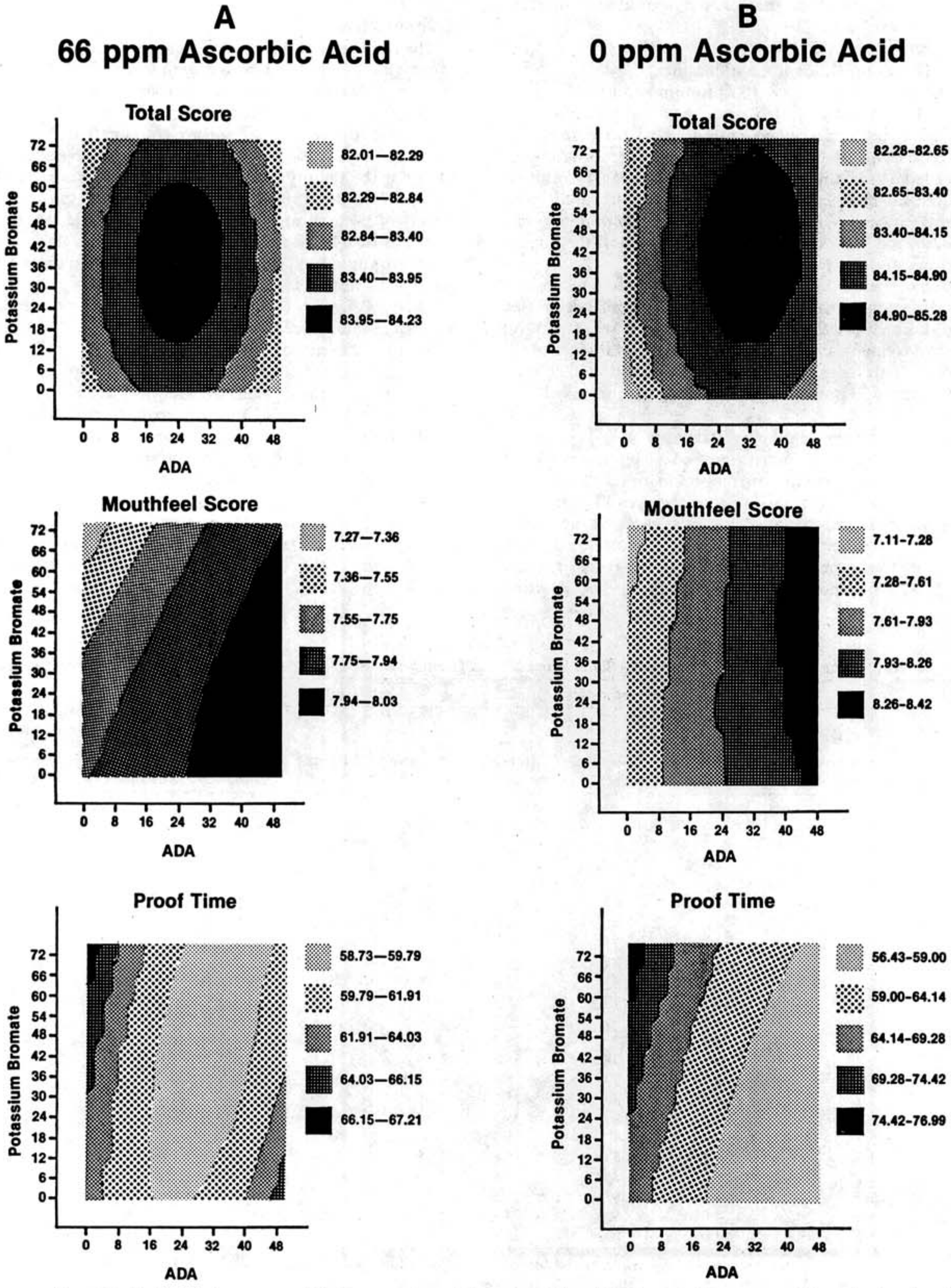

Fig. 1. Response-surface plots for the total score, mouthfeel score, and proof time. Ascorbic acid level was held constant at 66 ppm in plots in column **A** and at 0 ppm for the plots in column **B**.

the maximum response, and without any ascorbic acid 0–72 ppm potassium bromate and 18–42 ppm ADA produced the best external bread characteristics. A similar trend of oxidation requirements was evident in the internal score plots.

The absence of ascorbic acid (Fig. 1, plot B) also produced a better maximum response for the mouthfeel score. Here, the ADA requirement changed from 26–48 ppm in plot A to 39–48 ppm in plot B, whereas the potassium bromate effect differed only slightly between the two plots.

The minimum value desirable for the proof time response (Fig. 1), was best achieved when the ascorbic acid was excluded from the oxidation system (plot B). As for the mouthfeel and total scores, the major changes in the surface coutours of these proof time plots occurred along the ADA axis, indicating that ADA had a significant effect on the proof time and potassium bromate had little effect. Figure 2 gives the contour plots for the break and shred score and for the grain score. Three plots are given for each of these characteristics. Plot A compares the interaction of potassium bromate and ADA in the presence of 66 ppm ascorbic acid. Plot B also shows the same interaction but in the absence of ascorbic acid. In the third plot (plot C) the ADA level was held constant at 22 ppm while potassium bromate and ascorbic acid were varied.

When comparing plots A and B for the break and shred score (Fig. 1), the maximum responses were given by 0–10 ppm potassium bromate, 0–24 ppm ADA, and 66 ppm ascorbic acid (plot A) and by 54–72 ppm potassium bromate, 0–16 ppm ADA, and 0 ppm ascorbic acid (plot B). When the ascorbic acid was removed from the system, the requirement for potassium bromate more than doubled while the ADA requirement decreased slightly. The influence of ascorbic acid on the potassium bromate effect for break and shred was also shown in plot C, where very little (0–4 ppm) potassium bromate and a large amount (112–120 ppm) of ascorbic acid with 22 ppm ADA were needed to obtain the maximum response. The presence of ascorbic acid in the oxidation system tended to reduce the potassium bromate requirement for a good break and shred score. Ascorbic acid also seemed to have a slight effect on the ADA requirement.

The grain score for the bread crumb was significantly affected by all three oxidants. In general, a higher level of ascorbic acid reduced the potassium bromate requirement and increased the tolerance to ADA (Fig. 2, plot A). Without ascorbic acid (plot B), the potassium bromate requirement increased slightly to a minimum of 18 ppm while the ADA levels decreased to less than 32 ppm. Plot C shows that as the ascorbic acid level was increased, less potassium bromate was needed. The differences in the maximum grain score responses for all three plots were very slight.

The plots for the specific volume and force index characteristics are given in Figure 3. Ascorbic acid caused the range of values for the maximum specific volume response to decrease from 5.65–5.73 (plot B, 0 ppm ascorbic acid) to 5.47–5.53 (plot A, 66 ppm ascorbic acid).

When ascorbic acid was left out of the oxidation system, the amount of potassium bromate needed for the maximum specific volume and minimum force index responses decreased, while the ADA requirement stayed relatively the same.

The plots for the force index indicate that the bread was significantly softer (lower minimum response) when no ascorbic acid was used. The softest bread was produced with 10–48 ppm of ADA and no more than 20 ppm of potassium bromate (plot B).

CONCLUSIONS

The second order response-surface analysis model was successful in predicting an optimum response for each of the loaf quality characteristics evaluated. The predicted optimum responses (whether minimum or maximum) were generally

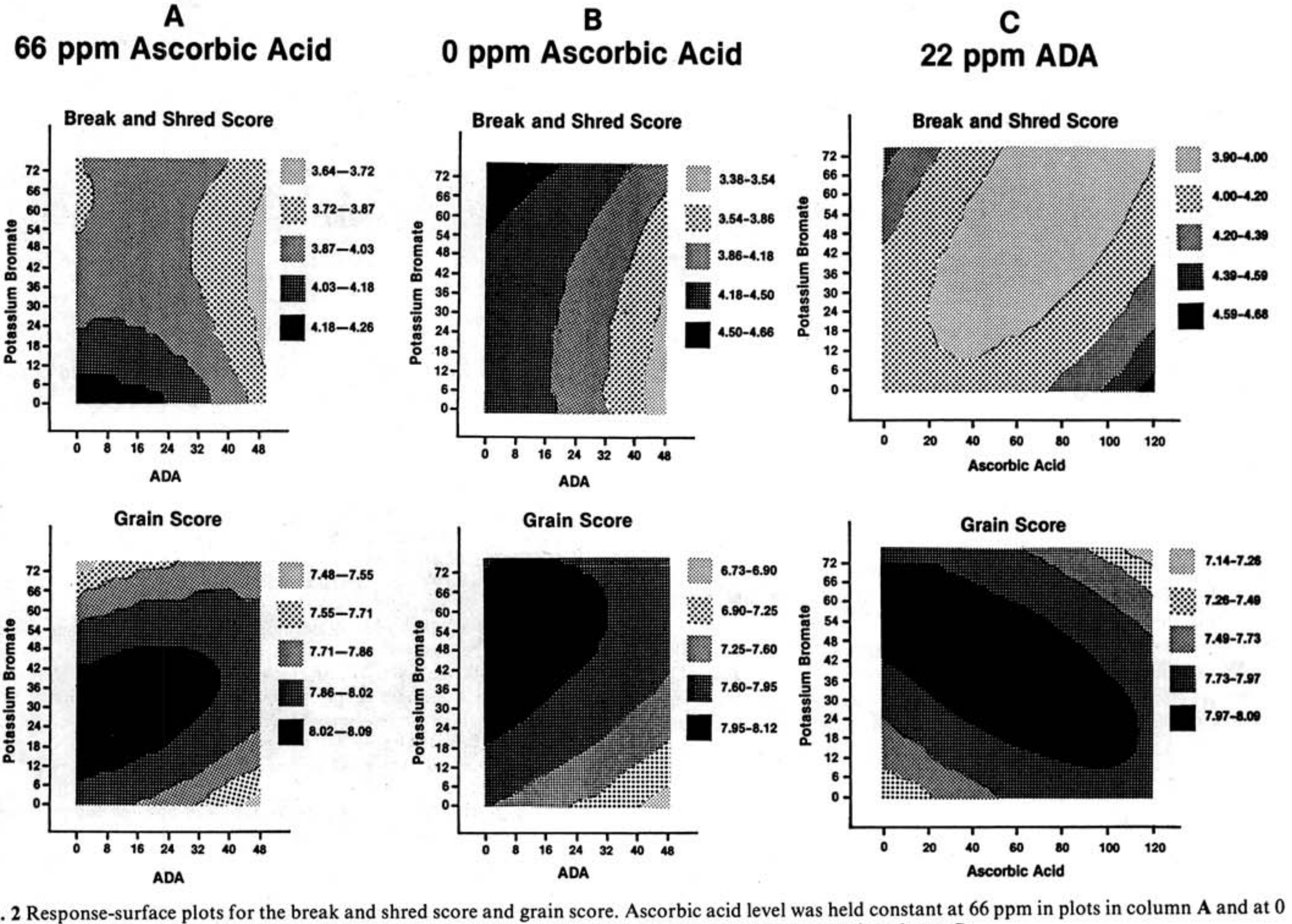

Fig. 2 Response-surface plots for the break and shred score and grain score. Ascorbic acid level was held constant at 66 ppm in plots in column **A** and at 0 ppm for the plots in column **B**. The azodicarbonamide level was held constant at 22 ppm for the plots in column **C**.

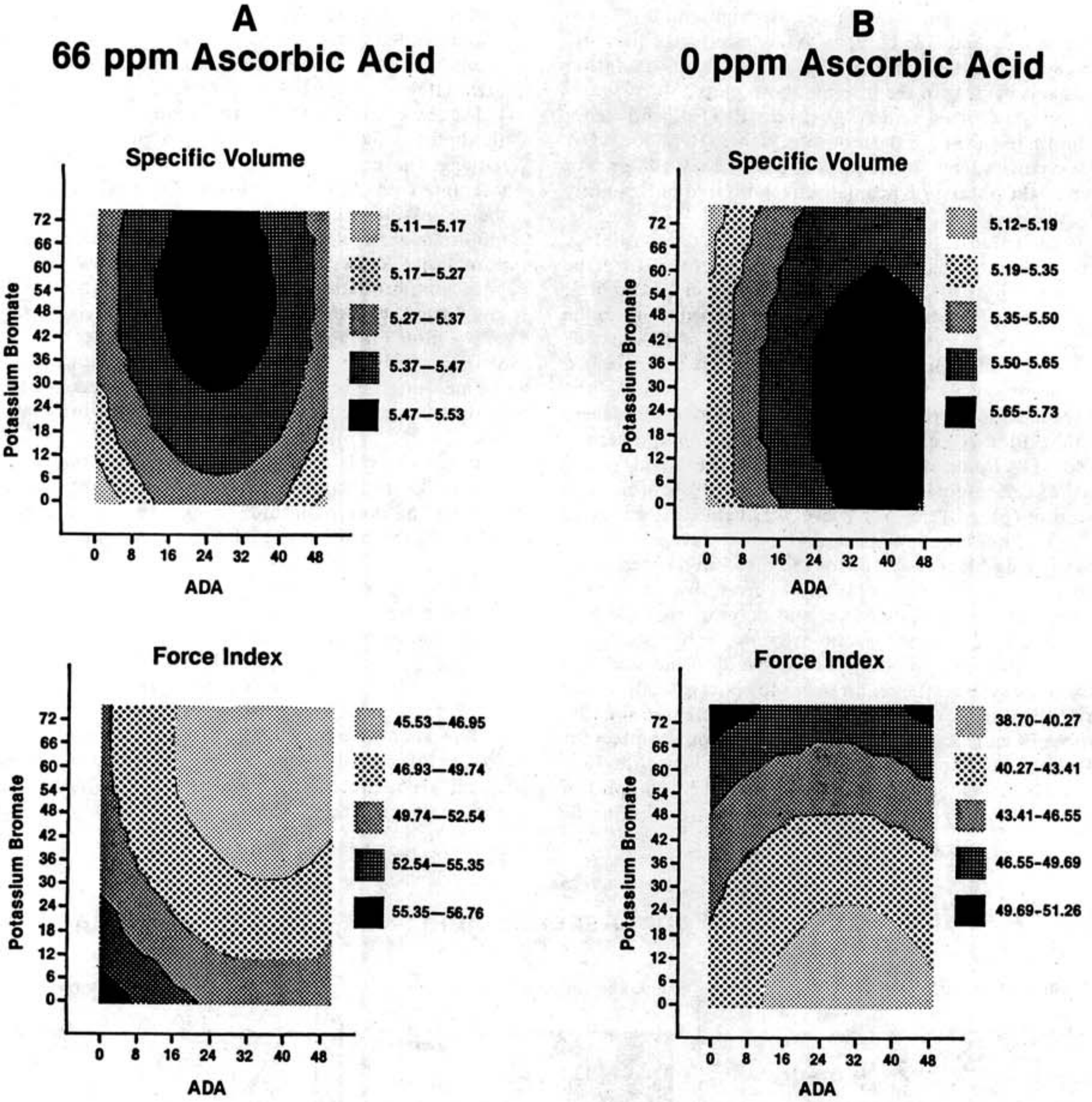

Fig. 3 Response-surface plots for the specific volume and force index characteristics. Ascorbic acid level was held constant at 66 ppm in plots in column **A** and at 0 ppm for the plots in column **B**.

produced with a combination of three oxidants: 39 ppm potassium bromate, 22 ppm ADA, and 66 ppm ascorbic acid. However, loaves that did not include ascorbic acid generally performed better than those that did.

Ascorbic acid also had an interesting effect on the potassium bromate requirement in the oxidation system. For the quality characteristics total score, break and shred score, and grain score, the contour plots showed that more potassium bromate was needed to obtain the maximum response when no ascorbic acid was used. The opposite was true for the specific volume and force index characteristics.

For the total score, mouthfeel score, proof time, and specific volume characteristics, when ascorbic acid was removed from the oxidation system, the contour plots showed an increase in the level of ADA needed to obtain the desired maximum or minimum responses. These trends indicate a definite interaction among the three oxidants that affects the quality characteristics, sometimes in different ways.

Further research should be undertaken in order to document the role of ascorbic acid in the oxidation system of no-time dough processes. Because no reducing agent was used in this study, it is also desirable to determine if the interactions here would differ in the presence of a reducing agent.

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