High α-Amylase Flours: Effect of pH, Acid, and Salt on the Rheological Properties of Dough

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ABSTRACT

When salt content in two doughs (pH 5.8), a control and one with 108 SKB units per 100 g of flour, was increased from 0.0 to 2.5%, the dough development times increased by 35.0 and 33.3%, respectively, whereas dough development time of a dough with 540 SKB units per 100 g of flour was negligibly affected. The pH 4.2 doughs of the control flour with and without salt and L-cysteine HCl (25 ppm) + $KBrO_3$ (75 ppm) showed negligible relaxation compared with those of the higher α-amylase flours. A highly significant correlation coefficient between the ratio figure and asymptotic load values, $r = 0.96$ ($r^2 = 0.92$), indicated that the two parameters were highly interrelated and measured the flow behavior of dough. On decreasing the pH of dough with 540 SKB units per 100 g of flour containing 1.5% salt from 5.8 to pH 5.0, the ratio figure and asymptotic load values were found to increase from 1.9 to 3.7 and from 240 to 423 g, respectively.

Extensive work has been reported on the effect of pH, acid, and salt variables on the rheological properties of normal flour doughs (Tanaka et al 1967, Barnes et al 1973, Galal et al 1978, Bakhoum and Ponte 1982). Acidification of flour has been suggested as a possible means to inactivate the high α-amylase activity in flours (Meredith 1970, Ibrahim and D'Appolonia 1979, Dorfer and Koball 1980, Harinder and Bains 1987). Information on the effect of salt and pH on the rheological properties and structural relaxation of doughs containing high α-amylase flour is limited. The purpose of this investigation was to evaluate the interrelationships of pH, acid, and salt with or without reducing (L-cysteine HCl) and oxidizing ($KBrO_3$) agents on the rheological properties of a control dough and doughs made with high α-amylase (108–540 SKB units per 100 g) flour, using farinograph and extensigraph techniques.

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MATERIALS AND METHODS

A 10-kg sample of an extensively grown bread wheat cultivar, WL 1562, was tempered to a moisture content of 15.5% in an airtight container for 48 hr at room temperature before being milled on the pneumatic Buhler laboratory mill (MLU 202) to an extraction of about 72% straight grade flour; this was designated "control flour" in this investigation. It contained 10.1% protein (N × 5.7), showed a diastatic activity of 220 mg/10 g (AACC 1976), and had a color grade of 1.9 (Henry Simon 1976; method 4.04). The high α-amylase flour blends containing 108 and 540 Sandstedt, Kneen, and Blish (SKB) units per 100 g were prepared by incorporating into the control flour sprouted-wheat flour of the same variety with an activity of 108 SKB units per 1 g, determined according to Perten (1966). The sprouted wheat was prepared from 1 kg of grain steeped to a moisture content of 42%, by germinating it at 20°C and 95% rh in a humidity-controlled chamber and drying it at 50°C for 24 hr. After the roots were removed, the sprouted grains were ground finely in the Falling Number AB Kamas mill, using a 0.8-mm sieve, and were used in various blends.

Adjusting pH

The amounts of 1*N* acid solutions that were used (ml/100 g of flour) to obtain pH 5.0 and 4.2 doughs were, respectively: acetic (2.0, 6.8), lactic (1.3, 4.0), hydrochloric (1.2, 2.5), and orthophosphoric (2.4, 6.7). The dough pH was checked at the dough development stage and after mixing for 15 min according to Holmes and Hoseney (1987). A measured aliquot of the acid and salt solution was mixed simultaneously with the water used for mixing the dough in the farinograph.

Salt (0.0, 1.5, and 2.5% flour weight basis) was used in the dough systems. L-cysteine HCl (M/S Hopkins and Williams Ltd., Essex, England), at levels of 25 and 50 ppm, was used in conjunction with potassium bromate (75 ppm) in doughs for extensigraph studies.

Farinograph Curves

The AACC (1976) constant flour method 54-21 was followed, and salt concentrations were varied with a view to recording changes in the mixing properties of dough. The farinograph curves were interpreted for changes in dough development time (DDT, in minutes), peak consistency (in BU), and mixing tolerance index (MTI, in BU).

Extensigraph Curves

AACC (1976) method 54-10, without salt, was followed in the doughs made with control flour as well as those containing high α-amylase flours. In the case of experimental doughs, salt concentrations of 0.0, 1.5, and 2.5% and L-cysteine HCl (25 or 50 ppm) + $KBrO_3$ (75 ppm) were incorporated; pH levels of 5.8, 5.0, and 4.2 were used; and extensigrams were evaluated for resistance to extension at 5 cm (*R*, in BU) and for extensibility (*E*, in millimeters). The ratio figure (RF) was obtained by dividing the value for *R* by the value for *E*. For study of changes in structural relaxation of dough due to pH, salt, and *L*-cysteine HCl + $KBrO_3$, the two-point method developed by Hlynka (1957) was followed. The extensigrams were developed after relaxation times of 5, 25, and 45 min after rounding and shaping of doughs. The values for "asymptotic" load (L_A') and structural relaxation constant (C′) of the dough were calculated as prescribed by the author:

$$\text{Asymptotic load } L_A'\text{ (g)} = \frac{(L_2 t_2) - (L_1 t_1)}{t_2 - t_1}\text{, and}$$

$$\text{Structural relaxation constant } C'\text{ (g/min)} = \frac{t_1 t_2}{t_2 - t_1}(L_1 - L_2)\text{ ,}$$

TABLE I
Effect of pH, Acids, and Salt on the Mixing Properties of Control Flour and High α-Amylase (108 SKB units/100 g) Flour

Acid	pH	Salt (%)	Dough Development Time (min): Control	Dough Development Time (min): High α-Amylase Flour	Peak Consistency (BU): Control	Peak Consistency (BU): High α-Amylase Flour	Mixing Tolerance Index (BU): Control	Mixing Tolerance Index (BU): High α-Amylase Flour
None[a]	5.8	0.0	6.0	1.5	500	495	45	65
	5.8	1.5	7.1	3.0	465	410	25	25
	5.8	2.5	8.1	2.0	465	425	15	15
Acetic	5.0	0.0	4.2	2.0	510	430	45	60
	5.0	1.5	8.0	1.0	430	430	20	70
	5.0	2.5	8.8	1.5	430	430	20	40
	4.2	0.0	3.8	1.0	520	460	65	90
	4.2	1.5	1.5	1.2	440	420	30	80
	4.2	2.5	1.8	1.2	440	405	35	80
Lactic[a]	5.0	0.0	4.8	1.2	510	460	55	70
	5.0	1.5	1.6	1.2	465	425	35	80
	5.0	2.5	1.6	1.4	460	400	30	50
	4.2	0.0	3.5	1.2	510	490	75	110
	4.2	1.5	1.5	1.2	460	415	75	90
	4.2	2.5	1.5	1.2	440	405	35	60
Hydrochloric	5.0	0.0	5.0	1.3	470	480	25	100
	5.0	1.5	1.25	1.3	420	425	50	80
	5.0	2.5	1.5	1.5	440	435	30	85
	4.2	0.0	4.75	1.4	470	465	10	80
	4.2	1.5	1.75	1.4	420	450	30	90
	4.2	2.5	1.5	1.4	420	445	40	65
Orthophosphoric	5.0	0.0	5.5	1.3	495	470	20	85
	5.0	1.5	1.5	1.4	450	430	35	70
	5.0	2.5	1.5	1.4	430	450	20	80
	4.2	0.0	4.5	1.5	530	505	20	100
	4.2	1.5	1.6	1.5	435	420	35	80
	4.2	2.5	1.5	1.5	430	435	45	105
Mean pH								
5.8			7.1	2.17	476.7	443.3	28.3	35.0
5.0			3.8	1.38	459.2	438.8	32.1	72.5
4.2			2.4	1.31	459.6	442.9	41.3	85.8
LSD[b,c]			2.0	0.44	17.0	NS[d]	NS	16.1
Mean salt (%)								
0.0			5.0	1.41	501.3	478.3	41.3	79.6
1.5			3.9	1.85	448.3	421.3	34.2	61.7
2.5			4.3	1.59	445.8	425.4	26.3	52.1
LSD[c]			NS	0.33 ($P < 0.05$)	17.0 ($P < 0.05$)	18.7	NS	16.1

[a] Harinder and Bains (1988).
[b] Least significant difference.
[c] $P < 0.01$.
[d] Nonsignificant.

where L_1 and L_2 stand for load (BU) at 5 cm extension after relaxation times of t_1 (25 min) and t_2 (45 min), respectively.

The results were examined statistically by analysis of variance (Snedecor and Cochran 1967). The factorial designs of the farinograph and extensigraph experiments comprised four acids $\times$ three pHs $\times$ three salt concentrations, and three rest periods $\times$ three pHs $\times$ three salt concentrations, respectively. To compare the significance of differences between any two treatment mean values, least significant differences (LSD) ($P < 0.01$ or $P < 0.05$) were calculated. The interrelationship between RF and L_A' and L_A' versus C' was determined by calculating the coefficient of correlation between these parameters of dough properties.

RESULTS AND DISCUSSION

Farinograms

Statistical analysis of the data in Table I, which included the results of lactic acid as well for comparison (Harinder and Bains 1988), showed that the effect of pH on the overall mean values for DDT and peak consistency (BU) of control flour doughs was statistically significant ($P < 0.01$). As the pH of dough was decreased from 5.8 to 4.2, the overall mean values for DDT and peak consistency decreased by 66.2 and 3.6%, respectively. The effect of pH on the differences between the overall mean values for MTI of the control flour doughs were nonsignificant compared to the significant effect of pH on the MTI values for high α-amylase flour doughs. The mean values for DDT of pH 5.8 dough of high α-amylase flour significantly exceeded the mean values for pH 5.0 and pH 4.2 doughs. However, the differences between the mean values for peak consistencies of different pH doughs of high α-amylase flour were nonsignificant. As the salt content of high α-amylase flour dough was increased from 0.0 to 2.5%, the mean values for DDT, peak consistency, and MTI decreased significantly. As concentration of salt in the doughs of both control and high α-amylase flours was increased from 0.0 to 2.5%, the peak consistencies decreased by significant margins of 55.5 and 52.9 BU, respectively.

The effect of pH and salt on the MTI of control flour doughs and doughs with 108 and 540 SKB units per 100 g of flour is shown in Figs. 1–3, respectively. The pH 5.8 doughs of any of these flours containing 2.5% salt exhibited maximum tolerance to mixing, as shown by decreased MTI values. As the pH levels of these doughs were decreased to 4.2, mixing tolerance of dough decreased considerably, as shown by the increased MTI values. As pH of the dough was decreased, the MTI values increased, whereas addition of salt at the higher pH tended to counteract the adverse effect on the mixing properties of dough containing 2.5% salt (Fig. 3). Differences in the mean values for DDT and MTI due to acids were nonsignificant, except for the consistency differences of control flour dough, which were significant ($P < 0.01$).

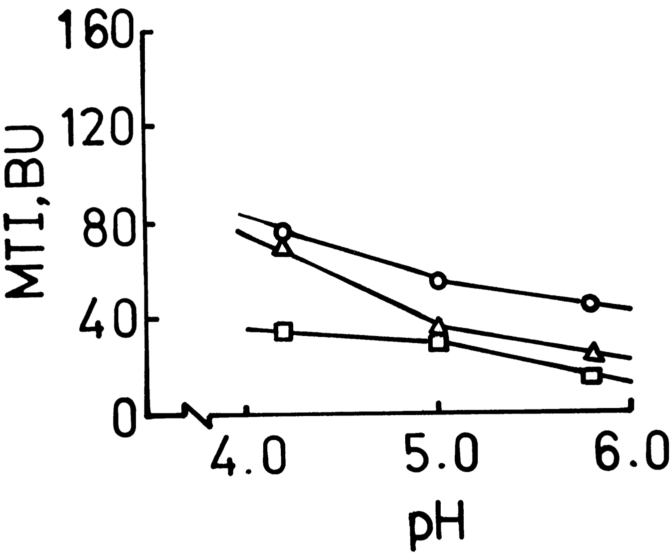

Fig. 1. Effect of pH and salt on the mixing tolerance index (MTI) values (BU) of control flour. Salt: 0.0 (○—○), 1.5 (△—△), 2.5 (□—□).

Extensigrams

Statistical examination of the results in Tables II and III, including mean results of extensigrams taken at 25-min intervals as well, showed that the relaxation time and pH of doughs had a significant effect on the extensibility and RF values ($P < 0.01$) of the control flour doughs and the doughs with 108 SKB units per 100 g of flour. Although the amount of salt had no significant effect on the extensibility of doughs of both the flours, its effect on RF values was significant ($P < 0.01$). This was found to be the result of increased resistance of salt-containing doughs to extension. The RF values of pH 4.2 doughs were significantly higher than those of pH 5.8 and pH 5.0 doughs despite L-cysteine HCl (25 ppm) + $KBrO_3$ additives in those doughs. The doughs of control flour containing 0.0, 1.5, and 2.5% salt had mean RF values of 3.5, 8.4, and 9.1, respectively (LSD 2.7, $P < 0.01$) compared to the RF values of 2.8, 6.6, and 7.7, respectively (LSD 2.17, $P < 0.01$) of the doughs containing 108 SKB units per 100 g of flour. The mean RF value of the high α-amylase flour

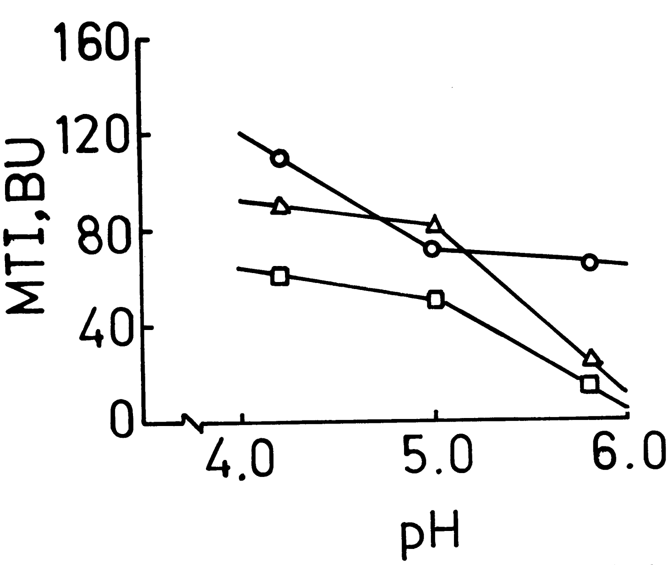

Fig. 2. Effect of pH and salt on the mixing tolerance index (MTI) values (BU) of high α-amylase flour containing 108 SKB units per 100 g. Salt: 0.0 (○—○), 1.5 (△—△), 2.5 (□—□).

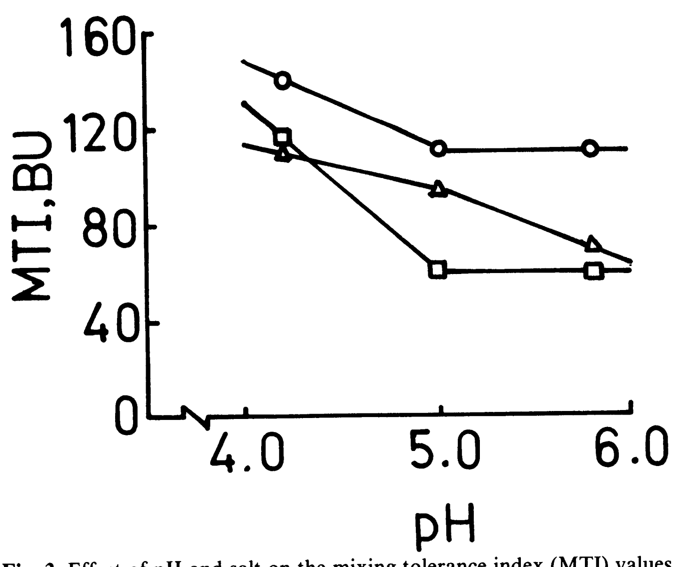

Fig. 3. Effect of pH and salt on the mixing tolerance index (MTI) values (BU) of high α-amylase flour containing 540 SKB units per 100 g. Salt: 0.0 (○—○), 1.5 (△—△), 2.5 (□—□).

dough was 21.6% lower than that of the control flour dough when relaxed for 45 min compared to a decline of 20.8% when the doughs contained L-cysteine HCl + $KBrO_3$. The mean RF value of the pH 4.2 dough of a high α-amylase flour was 20.0% below that of the control and 21.7% lower than that of doughs containing L-cysteine HCl + $KBrO_3$. The pH 4.2 doughs of control flour were short and showed little improvement on relaxation.

The pH 5.8, 5.0, and 4.2 doughs of flour with 540 SKB units per 100 g of flour without L-cysteine HCl + $KBrO_3$, when rested for 45 min, showed increases of 36.7, 36.3, and 43.4%, respectively, in extensibility over doughs rested 5 min (Table IV). The pH 4.2 doughs of this flour with and without the additives were characterized as short because of their high RF values of 7.6–9.1 compared to 1.9 and 3.7 of pH 5.8 and pH 5.0 doughs, respectively.

TABLE II
Effect of Relaxation, pH, Salt, and L-Cysteine HCl + $KBrO_3$ on the Extensigram Parameters of a Control Flour Dough

		Dough Relaxation						Mean Values	
		5 min			45 min				
pH	Salt (%)	E[a] (mm)	R[b] (BU)	RF[c] (R/E)	E[a] (mm)	R[b] (BU)	RF[c] (R/E)	E[a] (mm)	RF[c] (R/E)
Without L-cysteine + $KBrO_3$									
5.8	0.0	78	605	7.8	133	280	2.1		
	1.5	97	830	8.6	142	430	3.0		
	2.5	97	920	9.5	147	550	3.7		
5.0	0.0	96	495	5.2	131	250	1.9		
	1.5	78	>1,000	>12.8	130	595	4.6		
	2.5	81	>1,000	>12.3	130	750	5.8		
4.2	0.0	90	470	5.2	117	215	1.8		
	1.5	65	>1,000	>15.4	94	>1,000	>10.6		
	2.5	68	>1,000	>14.7	83	>1,000	>12.0		
Mean pH									
5.8								123	4.5
5.0								109	6.6
4.2								89	9.5
LSD[d,e]								16	2.7
Mean salt (%)									
0.0								112	3.5
1.5								105	8.4
2.5								105	9.1
LSD[e]								NS[f]	2.7
Mean dough relaxation (min)									
5								83	10.2
25								115	5.8
45								123	5.1
LSD[e]								16	2.7
With L-cysteine HCl (25 ppm) + $KBrO_3$ (75 ppm)									
5.8	0.0	123	425	3.5	123	205	1.7		
	1.5	115	680	5.9	152	330	2.2		
	2.5	87	>1,000	>11.5	131	720	5.5		
5.0	0.0	99	395	4.0	128	235	1.8		
	1.5	89	870	9.8	121	550	4.5		
	2.5	109	880	8.1	155	440	2.8		
4.2	0.0	132	160	1.2	102	210	2.1		
	1.5	66	>1,000	>15.2	95	>1,000	>10.5		
	2.5	70	>1,000	>14.3	82	>1,000	>12.2		
Mean pH									
5.8								122	4.7
5.0								124	4.5
4.2								90	9.2
LSD[e]								26	3.6
Mean salt (%)									
0.0								118	2.2
1.5								109	7.6
2.5								110	8.7
LSD[e]								NS	3.6
Mean dough relaxation (min)									
5								99	8.2
25								116	5.5
45								121	4.8
LSD[g]								19	2.6

[a] Extensibility.
[b] Resistance to extension at 5 cm.
[c] Ratio figure.
[d] Least significant difference.
[e] $P < 0.01$.
[f] Nonsignificant.
[g] $P < 0.05$.

A considerable variation in the RF values (2.9–13.7) for Indian wheats has been reported by Bains and Irvine (1965). A good baking quality wheat variety (NP 824) had an RF value of 4.4 and that of another good baking quality wheat variety grown in four locations varied from 2.9 to 5.6.

Structural Relaxation Constants

The values for L_A' for the control flour doughs and the high α-amylase flour doughs of varying pH and salt contents were in the range of 83.8–575 and 146.2–812.5 L_A', respectively (Table V). For the dough with 540 SKB units per 100 g of flour, the

TABLE III
Effect of Relaxation, pH, Salt, and L-Cysteine HCl + $KBrO_3$ on the Extensigram Parameters of a High α-Amylase Flour (108 SKB units/100 g) Dough

		Dough Relaxation						Mean Values	
		5 min			45 min				
pH	Salt (%)	E[a] (mm)	R[b] (BU)	RF[c] (R/E)	E[a] (mm)	R[b] (BU)	RF[c] (R/E)	E[a] (mm)	RF[c] (R/E)
Without L-cysteine + $KBrO_3$									
5.8	0.0	103	590	5.7	144	250	1.7		
	1.5	112	780	7.0	166	405	2.4		
	2.5	106	990	9.3	156	520	3.3		
5.0	0.0	89	405	4.6	135	215	1.6		
	1.5	100	970	9.7	149	530	3.6		
	2.5	103	950	9.2	147	680	4.6		
4.2	0.0	103	325	3.2	111	230	2.1		
	1.5	77	>1,000	>13.0	110	820	7.5		
	2.5	85	970	11.4	94	860	9.1		
Mean pH									
5.8								136	4.3
5.0								123	5.2
4.2								99	7.6
LSD[d,e]								14	2.2
Mean salt (%)									
0.0								119	2.8
1.5								122	6.6
2.5								117	7.7
LSD[e]								NS[f]	2.2
Mean dough relaxation (min)									
5								98	8.1
25								126	5.0
45								135	4.0
LSD[e]								14	2.2
With L-cysteine HCL (25 ppm) + $KBrO_3$ (75 ppm)									
5.8	0.0	143	250	1.7	131	170	1.3		
	1.5	121	585	4.8	165	325	2.0		
	2.5	122	810	6.6	154	390	2.5		
5.0	0.0	120	225	1.9	139	155	1.1		
	1.5	105	740	7.0	145	480	3.3		
	2.5	100	970	9.7	147	650	4.4		
4.2	0.0	141	175	1.2	103	160	1.6		
	1.5	88	980	11.1	111	850	7.7		
	2.5	78	>1,000	>12.8	97	>1,000	>10.3		
Mean pH									
5.8								142	2.8
5.0								128	4.2
4.2								103	7.2
LSD[e]								22	2.4
Mean salt (%)									
0.0								127	1.4
1.5								126	5.6
2.5								121	7.2
LSD[e]								NS	2.4
Mean dough relaxation (min)									
5								113	6.3
25								128	4.1
45								132	3.8
LSD[g]								NS	1.8

[a] Extensibility.
[b] Resistance to extension at 5 cm.
[c] Ratio figure.
[d] Least significant difference.
[e] $P < 0.01$.
[f] Nonsignificant.
[g] $P < 0.05$.

TABLE IV
Effect of Relaxation, pH, and L-Cysteine HCl + $KBrO_3$ on the Extensigram Parameters of High α-Amylase Flour (540 SKB Units/100 g) Doughs Made with 1.5% Salt

			Dough Relaxation					
			5 min			45 min		
pH	L-Cysteine HCl (ppm)	$KBrO_3$ (ppm)	E[a] (mm)	R[b] (BU)	RF[c] (R/E)	E[a] (mm)	R[b] (BU)	RF[c] (R/E)
5.8	0.0	0	128	660	5.2	175	340	1.9
5.0	0.0	0	102	>1,000	>9.8	139	510	3.7
4.2	0.0	0	83	>1,000	>12.1	119	975	8.2
4.2	25	75	95	1,000	10.5	108	980	9.1
4.2	50	75	110	840	7.6	111	840	7.6

[a] Extensibility.
[b] Resistance to extension at 5 cm.
[c] Ratio figure.

TABLE V
Effect of pH, Salt, and L-Cysteine HCl + $KBrO_3$ on the Structural Relaxation of Control Dough and High α-Amylase Flour (108 SKB units/100 g) Dough

		Relaxation Constant C′ (g/min)		Asymptotic Load L_A' (g)	
pH	Salt (%)	Control Flour	High α-Amylase Flour	Control Flour	High α-Amylase Flour
Without L-cysteine HCL + $KBrO_3$					
5.8	0.0	2,813	2,813	217.5	187.5
	1.5	3,094	4,219	361.3	311.5
	2.5	2,250	6,188	500.0	382.5
5.0	0.0	1,125	3,094	225.0	146.2
	1.5	5,344	2,250	476.3	480.0
	2.5	7,875	11,813	575.0	417.5
4.2	0.0	5,906	1,125	83.8	205.0
	1.5	NR[a]	8,438	NR	632.5
	2.5	NR	6,188	NR	722.5
With L-cysteine HCL (25 ppm) + $KBrO_3$ (75 ppm)					
5.8	0.0	2,531	563	148.8	157.5
	1.5	3,938	3,094	242.5	256.3
	2.5	6,750	2,250	570.0	340.0
5.0	0.0	844	281	216.5	149.0
	1.5	1,125	1,125	525.0	455.0
	2.5	5,625	2,531	315.0	593.8
4.2	0.0	···	···	253.5	166.3
	1.5	NR	1,688	NR	812.5
	2.5	NR	NR	NR	NR

[a] No relaxation.

TABLE VI
Effect of pH, L-Cysteine HCl, and $KBrO_3$ on the Structural Relaxation of High α-Amylase Flour (540 SKB units/100 g) Doughs Made with 1.5% Salt

pH	L-Cysteine HCl (ppm)	$KBrO_3$ (ppm)	Relaxation Constant C′ (g/min)	Asymptotic Load, L_A' (g)
5.8	0.0	0.0	4,500	240
5.0	0.0	0.0	3,938	423
4.2	0.0	0.0	281	969
4.2	25.0	75.0	···	993
4.2	50.0	75.0	···	890

values for L_A' ranged from 240 to 993 g, depending on the pH of the dough containing 1.5% salt (Table VI). A highly significant correlation coefficient between RF and L_A' values, $r = 0.96$ ($r^2 = 0.92$), indicated that the two parameters were highly associated and that both reflected the flow behavior of the dough. According to Bains and Irvine (1965), the RF values for Canadian bread wheat Grades No. 1 and 2 were in the range of 1.15–1.26, unlike the generally high RF values for Indian wheats. The L_A' range of Indian wheats was higher than for the Canadian flour doughs, which ranged from 66 to 252 L_A' (Hlynka, 1957), as recalculated from the author's regression. The values for C′ varied considerably, depending on pH and the amount of salt in the doughs of control and high α-amylase flours. The pH 5.8 and 5.0 doughs without salt showed greater structural relaxation, unlike the pH 4.2 doughs, which in several cases showed no relaxation. However, an increase generally occurred in C′ when relaxation became slower, and vice versa. The correlation coefficient between C′ and L_A' values was found to be $r = 0.34$ ($r^2 = 0.116$), which implied a low degree of association between these parameters of dough. When the pH of doughs with 540 SKB units per 100 g of flour and 1.5% salt was decreased from 5.8 to 5.0 and 4.2, the values for L_A' increased by about 76.4% and threefold, respectively (Table VI). L-cysteine HCl (50 ppm) + $KBrO_3$ in the dough containing salt reduced the L_A' value by about 8.2%. The higher dosage of $KBrO_3$ with L-cysteine HCl simulated a condition for the chemical development of dough (Kaur and Bains 1979) using a control flour and a high α-amylase flour for comparison of their rheological properties.

Thus, pH, salt, and relaxation time exert considerable influence on the rheological properties of dough. These changes are ascribed to possible conformational changes in the gluten and on the enzymes in the flour (Kozmin 1933, Bayfield and Young 1964, Bennett and Ewart 1965, Smith and Mullen 1970, Pyler 1973, Bernardin 1978, Huber 1978, McCrate et al 1981, Salovaara 1982, Lorenz et al 1983). Minimizing the adverse effect of high α-amylase activity of flour by decreasing the pH of dough containing salt and using the additives L-cysteine HCl + $KBrO_3$ to eliminate bulk fermentation of dough seemed to improve the baking potential of high α-amylase flour doughs (Harinder and Bains 1988).

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