

# Effects of Additives on Flour-Water Dough Mixograms<sup>1</sup>

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## ABSTRACT

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The effects on bread flour-water mixing curves of different water amounts and addition of various ingredients were measured with a 35-g computerized, fixed-bowl mixograph. Water was varied from 58 to 70% in 3% increments, and the additives were tested at two concentrations. The additives were classed by function: vital gluten (regular, modified, and enhanced), oxidants (ascorbic acid, potassium iodate, azodicarbonamide, and potassium bromate), a reductant (L-cysteine), surfactants (sodium stearoyl lactylate and sucrose ester), salts (sodium chloride, potassium chloride, potassium nitrate, sodium sulfate, calcium chloride, and magnesium sulfate), and other (malt and calcium propionate). Across all additives and concentrations, increasing water lengthened the time

to midline peak. The change was not linear but averaged about 0.15 min for each 1% increase in water. Midline peak heights decreased nearly linearly by about 1.5 scale percent for each 1% increase in water. Salts increased time to peak and peak height. Vital gluten increased peak height but decreased time to peak resistance, as compared with the control. Cysteine shortened peak times, but the oxidants had little effect. Neither had a major effect on peak heights. The surfactant sodium stearoyl lactylate increased time to peak but had relatively little effect on peak height. The reductant cysteine reduced total work required to mix to peak by about 20%, but salts increased work by about 40%.

Dough conditioners have been used as additives in bakery products for about 50 years to improve dough handling characteristics, eating quality, and shelf life (Stauffer 1983, Fitchett and Frazier 1987). Dough conditioners may be grouped into four categories: surfactants (e.g., sodium stearoyl lactylate [SSL]), oxidants (e.g., bromate), reductants (e.g., L-cysteine), and mixing-time reducers (e.g., proteases) (Stauffer 1983). Flour and water can be mixed into a viscoelastic dough, but the rheology of the resultant dough changes in different ways as the amount and kind of dough conditioner varies (Danno and Hosney 1982).

Surfactants such as SSL and sucrose esters (SE) are generally believed to increase mixing time. Watson and Walker (1986) reported that SE added to bread flour in powder form increased the mixograph mixing time. Mixing time of doughs containing SSL tended to increase with increased concentration, but stability decreased. Tsen and Weber (1981) reported an increase in the curve's stability when SSL was added in solution to yeasted doughs.

Moore and Herman (1942) found that increasing amounts of iodate- and phosphate-type dough conditioners increased farinograph absorption, but increasing amounts of potassium bromate (KBrO<sub>3</sub>) decreased absorption.

Fitchett and Frazier (1987) pointed out that azodicarbonamide (ADA) shortened the dough development time and decreased tolerance to overmixing. They also stated that doughs containing L-ascorbic acid (AA) were more tolerant of over- or undermixing, and that L-cysteine reduced the energy requirement to mix the doughs to optimum development.

Weak et al (1977) reported a rapid breakdown and an extremely narrow mixogram tail width with the addition of the fast acting-oxidants potassium iodate (KIO<sub>3</sub>), ADA, and KBrO<sub>3</sub> at pH 4.7. However, the slower-acting oxidants, ascorbic acid (AA) and KBrO<sub>3</sub> at pH 6.0, had little effect on the mixogram curve. They also found that cysteine shortened the required mixing time, as determined by the mixograph.

Danno and Hosney (1982), using a 10-g mixograph, found that sodium chloride increased the band width and the peak height of the mixogram curve, along with increasing the mix time. Potassium chloride (KCl) and sodium chloride (NaCl) were found to increase mixing time (Roach 1989). Other authors have also reported an increase in mixing time with the addition of NaCl (Moore and Herman 1942, Hlynka 1962).

The objective of this work was to study the combined effects of various dough conditioners and absorptions on mixograph

peak time, peak height, and area under the curve (the work input needed to bring the dough to peak development).

## MATERIALS AND METHODS

### Flour

A commercially mixed hard red winter wheat bread flour (donated by Cargill, Inc., Wichita, KS) was used (moisture 12.4%, protein 12.5%, ash 0.44%; values reported on an as-is basis).

### Additives

The additives chosen included those most commonly used and others that might be used. Midwest Grain Co. (Atchinson, KS) provided a standard vital gluten. An enhanced gluten with vitamin and emulsifier was provided by Pennwalt Corporation (Flour Service Division, North Kansas City, KS), and vital gluten modified with soy lecithin was obtained from Wilke International, Inc. (Olathe, KS). All vital glutes were added in powder form at 2.5 and 5% concentrations on a flour-weight basis. Concentrations chosen were in the range used in bread products.

Cargill Inc. provided barley malt, added at 0.2 and 0.5% as a powder. The SE F-160, supplied by DKS International, Inc. (Tokyo, Japan), was also added in dry form at 1 and 2%. Pennwalt Corp. supplied the ADA, which was added at levels between 0.001 and 0.003%. KBrO<sub>3</sub> was added at 50 and 75 ppm, SSL at 0.25 and 0.5%, calcium propionate at 0.13 and 0.2%, AA at 150 and 200 ppm, and L-cystine at 20 and 25 ppm.

The remaining additives were reagent grade and added as aqueous solutions at 1.3 and 2.6% concentrations: calcium chloride (CaCl<sub>2</sub>), potassium nitrate (KNO<sub>3</sub>), magnesium sulfate (MgSO<sub>4</sub>), sodium sulfate (Na<sub>2</sub>SO<sub>4</sub>), potassium chloride (KCl), sodium chloride (NaCl), and potassium iodate (KIO<sub>3</sub>).

### Mixograph

A 35-g mixograph (National Manufacturing Div., TMCO, Inc., Lincoln, NE) was modified in this laboratory by connecting it to an AT-compatible computer via a load cell. The bowl was fixed at the 50% relative pen position, and the resistance of the dough to mixing caused a variable voltage signal to be generated by the load cell signal conditioner. This analog voltage signal was recorded on a strip chart, and the digitized equivalent was saved to a file on a floppy diskette. A compiled BASIC program was used to collect the data and plot it in a form resembling a conventional mixogram and to derive various parameters normally associated with a mixogram (Walker and Walker 1990). This computerized mixograph and the program are now commercially available through TMCO.

### Measurements

The mixograms were run on a 14% moisture basis, following the procedure outlined by AACC method 54-40A (1983), except

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for the modifications imposed by the fixed bowl. Five different water additions were used, and each sample was run in triplicate. The computer program was written to mathematically determine the mixing time to midline peak and the magnitude of the peak dough resistance. The area under the mixing curve to the midline was determined manually by planimeter, in arbitrary units. The area under the curve is a quantitative measure of the work required to mix a dough to peak development and was defined as the area under the curve center line from the beginning to the peak time.

The three replicates were analyzed by a response surface method (RSM). RSM was used to predict values from which figures were drawn. This program, originally described by Walker and Parkhurst (1984), uses a second-order multiple regression equation and currently runs under MS-DOS. RSM was chosen because it generates an equation that can be used to conveniently prepare a family of curves that shows two (or more) effects from interacting independent variables, such as additive concentration and water added. The original data points were used for the prediction equations, not the averages reported in the tables.

## RESULTS AND DISCUSSION

Tables I-III contain the averages for the three replicates for times to midline peak, peak heights, and areas under the curve

**TABLE I**  
Effect of Additives on Time (min) To Peak<sup>a</sup>

Type	Additive <sup>b</sup> Amount	Water Addition, %					
		58	61	64	67	70	
Control	...	3.6	3.7	4.0	4.4	5.2	
Vital Gluten	Standard	2.5%	3.8	3.9	4.1	4.5	5.1
		5.0%	3.6	3.9	4.0	4.8	5.1
Modified		2.5%	3.5	3.5	3.6	3.9	4.3
		5.0%	3.2	3.2	3.3	3.4	3.8
Enhanced		2.5%	3.6	3.6	4.1	4.3	5.0
		5.0%	3.0	3.1	3.3	3.7	4.3
Oxidants	AA	50 ppm	3.9	4.1	4.4	5.4	6.0
		200 ppm	4.0	4.0	4.1	5.1	6.0
KIO <sub>3</sub>		1.3%	3.9	4.0	4.2	4.6	5.4
		2.6%	4.3	4.3	4.5	5.0	5.7
ADA		0.001%	3.3	3.4	3.6	4.1	4.8
		0.003%	3.3	3.2	3.6	3.9	4.5
KBrO <sub>3</sub>		50 ppm	3.5	3.7	3.9	4.4	4.9
		75 ppm	3.6	3.6	4.0	4.3	5.1
Reductant	L-Cysteine	20 ppm	2.7	2.9	3.1	3.4	4.0
		25 ppm	2.6	2.7	2.9	3.2	3.6
Surfactants	SSL	0.25%	4.1	4.4	4.8	5.1	5.7
		0.50%	4.6	4.9	4.8	5.5	6.3
SE		1%	3.7	3.7	4.0	4.5	5.0
		2%	3.6	3.7	4.0	4.4	5.1
Salts	NaCl	1.3%	4.3	4.6	4.9	5.4	6.5
		2.6%	5.5	5.6	6.5	6.7	8.5
KCl		1.3%	4.2	4.5	5.0	5.6	6.5
		2.6%	5.1	5.2	5.6	6.2	7.4
KNO <sub>3</sub>		1.3%	4.1	4.2	4.3	4.9	5.8
		2.6%	4.4	4.2	4.5	4.8	5.6
Na <sub>2</sub> SO <sub>4</sub>		1.3%	5.2	5.4	6.1	7.1	9.1
		2.6%	8.0	9.2	11.4	15.3	21.7
CaCl <sub>2</sub>		1.3%	3.6	3.6	3.7	4.1	4.7
		2.6%	3.5	3.4	3.5	3.7	4.2
MgSO <sub>4</sub>		1.3%	4.7	4.7	5.2	6.0	7.4
		2.6%	6.6	7.2	8.3	10.3	13.7
Other additives	Malt	0.2%	3.5	3.7	3.9	4.5	5.3
		0.5%	3.7	3.8	4.3	4.5	5.4
Calcium propionate		0.13%	3.5	3.6	3.8	4.3	5.0
		0.2%	3.4	3.6	3.9	4.3	4.9

<sup>a</sup> Averages of three replications. Average standard deviation = 0.10 min.  
<sup>b</sup> AA = L-ascorbic acid, ADA = azodicarbonamide, SSL = sodium stearoyl lactylate, SE = sucrose esters.

for all the additives tested. The control values are an average of all controls run throughout the experiment period (three replicates on each day they were run).

## Water Addition Effects

The effects of changing water level on mixogram time to peak, peak height, and area under the curve (work) may be seen by examining the data in Tables I-III for any particular additive.

Time to peak increased as water addition increased, for all additives as well as for the control (Table I, Fig. 1). The response was greatest for the salts, especially the sulfates. The surfactant SSL and the oxidants generally had longer peak times than the control, and they tended to increase in peak time with increasing water in the same manner as the control. Vital gluten and the reductant, cysteine, generally increased peak time with increasing water, although cysteine did so somewhat less than the other additives. With the exception of the salt group, which was so strongly influenced by the sulfates, the average time to peak increased by about 0.15 min per 1% water increase, in the middle range. The sulfates increased much more rapidly with water addition than did other salts. Only the curve for oxidants was parallel to that of the control, the rest indicating interactions between additives and water.

**TABLE II**  
Effect of Additives on Peak Height<sup>a</sup> % of Scale

Type	Additive <sup>b</sup> Amount	Water Addition, %					
		58	61	64	67	70	
Control	...	61.4	56.0	51.7	46.5	42.1	
Vital Gluten	Standard	2.5%	71.5	64.9	60.1	56.4	51.8
		5.0%	80.9	80.2	74.0	69.0	60.4
Modified		2.5%	73.1	69.6	64.1	64.0	56.8
		5.0%	82.8	77.4	73.7	70.4	67.2
Enhanced		2.5%	70.8	67.7	63.2	60.2	57.9
		5.0%	79.7	83.1	77.1	64.7	54.7
Oxidants	AA	50 ppm	62.2	55.4	49.9	44.0	41.5
		200 ppm	52.7	48.1	45.7	39.5	35.9
KIO <sub>3</sub>		1.3%	70.0	64.4	60.2	55.9	51.8
		2.6%	74.1	68.3	64.4	60.1	56.1
ADA		0.001%	65.2	59.9	54.8	50.5	44.8
		0.003%	62.8	59.3	54.6	50.9	47.3
KBrO <sub>3</sub>		50 ppm	60.0	55.8	51.8	47.5	45.0
		75 ppm	62.1	57.0	50.4	47.8	43.9
Reductant	L-Cysteine	20 ppm	58.9	56.0	51.9	48.3	44.8
		25 ppm	63.1	54.0	50.5	48.6	44.4
Surfactants	SSL	0.25%	60.6	53.3	47.9	44.7	41.3
		0.50%	58.8	52.4	50.0	46.5	43.1
SE		1%	59.9	55.9	51.2	46.8	43.3
		2%	59.6	56.3	51.8	48.9	43.6
Salts	NaCl	1.3%	68.5	63.2	59.1	56.5	53.2
		2.6%	72.4	66.6	62.0	62.8	58.7
KCl		1.3%	63.4	58.4	52.4	49.6	46.0
		2.6%	70.7	65.3	61.8	58.5	54.8
KNO <sub>3</sub>		1.3%	66.7	61.2	57.9	53.7	48.0
		2.6%	60.1	55.3	58.3	53.6	49.9
Na <sub>2</sub> SO <sub>4</sub>		1.3%	76.6	70.5	72.4	65.3	57.6
		2.6%	74.7	72.7	70.1	67.6	64.2
CaCl <sub>2</sub>		1.3%	55.7	52.8	51.3	48.5	45.3
		2.6%	60.9	56.9	55.3	52.3	48.7
MgSO <sub>4</sub>		1.3%	71.0	67.0	50.2	46.0	42.9
		2.6%	81.5	77.9	72.2	68.8	62.7
Other additives	Malt	0.2%	54.0	50.0	46.3	42.2	37.7
		0.5%	64.3	58.0	52.5	49.4	44.4
Calcium propionate		0.13%	68.2	61.5	56.6	52.4	48.5
		0.2%	63.0	58.8	55.4	52.0	48.6

<sup>a</sup> Averages of three replications. Average standard deviation = 0.96%.  
<sup>b</sup> AA = L-ascorbic acid, ADA = azodicarbonamide, SSL = sodium stearoyl lactylate, SE = sucrose esters.

Peak heights decreased nearly linearly with increasing absorption, for all additives (Table II, Fig. 2). Second-order regression gave a better fit, however. Although the actual peak height at any absorption varied with the specific additive, on the average, they all decreased by about 1.5 scale percentage points per each 1% increase in absorption.

The area under the mixing curve midline, from beginning till peak time, is influenced by water addition (Table III, Fig. 3). However, as peak height and time to peak are influenced in opposite directions, the change in area was much less pronounced. The area under the curve is an indication of the amount of work necessary to mix the dough to its optimum. The total work required increased substantially at water additions below 64% absorption, and the curves appear to have a minimum at about 67%.

The reductant, cysteine, required considerably less work input at any absorption than did the control flour. All other additives increased the total work required, most especially the salts and glutens, although for different reasons. The glutens increased the peak heights more than the salts, requiring more work input per unit time, but the salts extended mixing times drastically while the glutens actually reduced mixing time. This is the justification for the common practice of withholding common salt, NaCl, from bread dough until just before the end of mixing (Table I, control vs. 1.3% NaCl).

**TABLE III**  
Effect of Additives on Area<sup>a</sup> (arbitrary units)

Type	Additive <sup>b</sup>	Water Addition, %					
		58	61	64	67	70	
Control	...	540	494	471	456	457	
Vital Gluten	Standard	2.5%	663	613	593	579	589
		5.0%	747	791	702	703	721
	Modified	2.5%	616	576	524	534	513
		5.0%	660	615	585	566	577
	Enhanced	2.5%	667	623	636	636	678
		5.0%	620	625	603	556	554
Oxidants	AA	50 ppm	603	546	520	528	538
		200 ppm	538	473	425	458	455
	KIO <sub>3</sub>	1.3%	612	548	515	521	520
		2.6%	694	628	593	583	583
	ADA	0.001%	503	460	436	443	423
		0.003%	469	431	419	412	423
KBrO <sub>3</sub>	50 ppm	541	508	486	476	506	
	75 ppm	558	502	473	480	513	
Reductant	L-Cysteine	20 ppm	405	406	385	381	387
		25 ppm	415	366	350	351	350
Surfactants	SSL	0.25%	613	582	558	529	534
		0.50%	712	657	585	589	602
	SE	1%	548	497	478	473	471
		2%	537	504	491	485	485
Salts	NaCl	1.3%	683	633	562	557	575
		2.6%	878	773	770	733	777
	KCl	1.3%	597	571	532	514	501
		2.6%	823	715	690	656	624
	KNO <sub>3</sub>	1.3%	643	593	545	547	557
		2.6%	636	558	565	540	550
	Na <sub>2</sub> SO <sub>4</sub>	1.3%	823	753	836	790	814
		2.6%	1,264	1,410	1,377	1,411	1,553
	CaCl <sub>2</sub>	1.3%	491	451	442	435	438
		2.6%	531	466	447	435	446
	MgSO <sub>4</sub>	1.3%	723	644	397	359	339
		2.6%	1,074	1,049	1,015	1,054	1,057
Other additives	Malt	0.2%	463	440	410	416	423
		0.5%	573	521	516	490	483

<sup>a</sup> Averages of three replications. Average standard deviations = 16 units.  
<sup>b</sup> AA = L-ascorbic acid, ADA = azodicarbonamide, SSL = sodium stearoyl lactylate, SE = sucrose esthers.

## Vital Glutens

The mixing time to peak development decreased with increased concentrations of the modified or enhanced vital glutens.

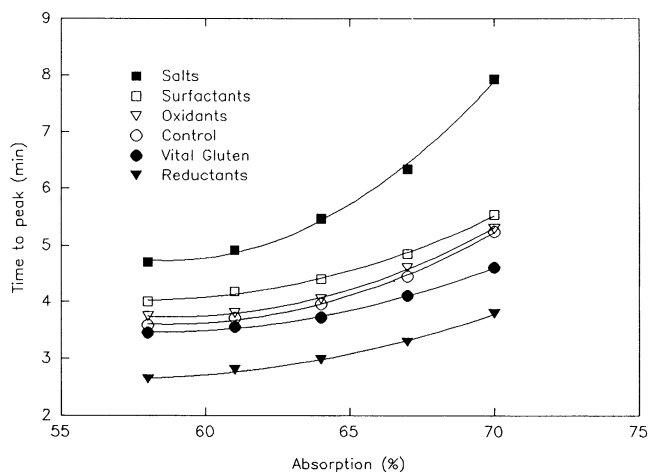
All three vital glutens increased the mixing curve peak height (Fig. 4) with increasing concentration. All vital glutens also increased the area under the curve (work to full development) compared with the control. The enhanced gluten produced the most change, followed by the modified gluten and then the normal product.

## Oxidants

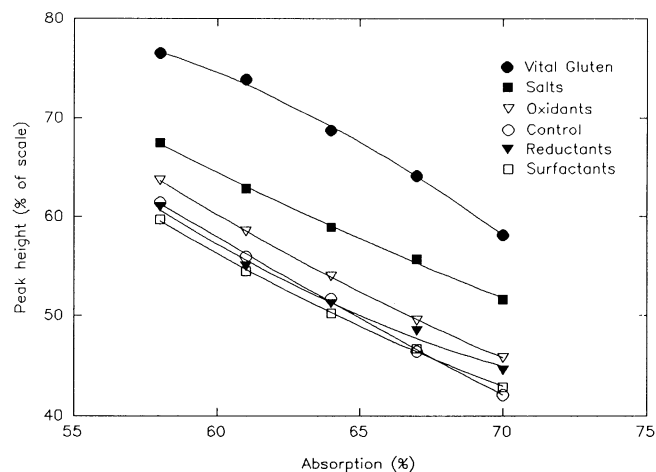
Additions to dough of either AA or KIO<sub>3</sub> increased the peak time in comparison with the control, whereas a decrease in peak time was noticed with increasing ADA concentrations. No significant change was noticed in mixing time with addition of KBrO<sub>3</sub>.

AA decreased peak height with increasing concentration. An increase in peak height was noted with KIO<sub>3</sub> (Fig. 5), however. Neither KBrO<sub>3</sub> nor ADA significantly changed peak height with increased concentrations.

AA at 150 ppm increased the area under the curve, but at the 200-ppm level of addition, the area remained almost the same or was lower than that of the control. KIO<sub>3</sub> increased both peak height and time; therefore, the area under the curve would naturally also increase with higher concentrations. Since no change was noticed in peak height or time with KBrO<sub>3</sub>, the area under the curve would not have been expected to change much.



**Fig. 1.** Effects of different additive classes on mixograph midline time to peak with changing absorption, arranged across concentrations and additives. Average standard deviation for three replicates = 0.10 min (coefficient of variation = 2.06%).



**Fig. 2.** Effects of different additive classes on mixograph midline peak heights with changing absorption, averaged across concentrations and additives. Average standard deviation for three replicates = 0.96 scale % units (coefficient of variation = 1.67%).

## Reductant

A reducing agent, such as L-cysteine, supposedly reduces the mixing time by cleaving a portion of the cross-linking disulfide bonds and creating free sulfhydryl groups. The overall effect is a decrease in the elastic strength of the gluten matrix (Stauffer 1983). Increasing additions of L-cysteine caused mix time to continually decrease (Fig. 6). This agrees with work by Weak et al (1977). However, the peak height value changed very little with an increase in cysteine concentration. The area under the curve

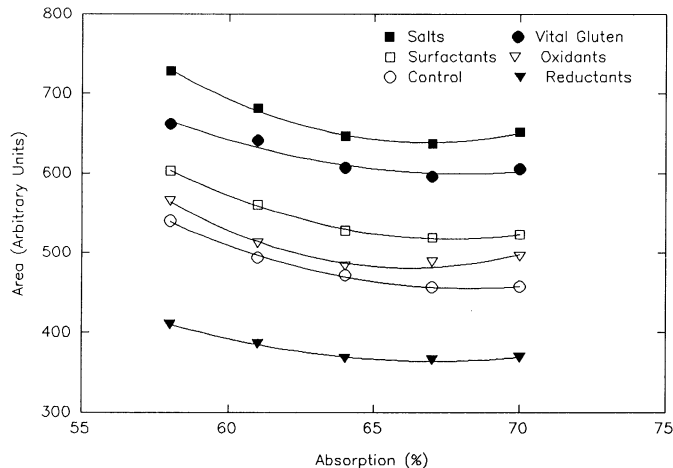


Fig. 3. Effects of different additive classes on mixogram midline area under the curve until peak with changing absorption, averaged across concentrations and additives. Average standard deviation for three replicates = 16 arbitrary units (coefficient of variation = 2.75%).

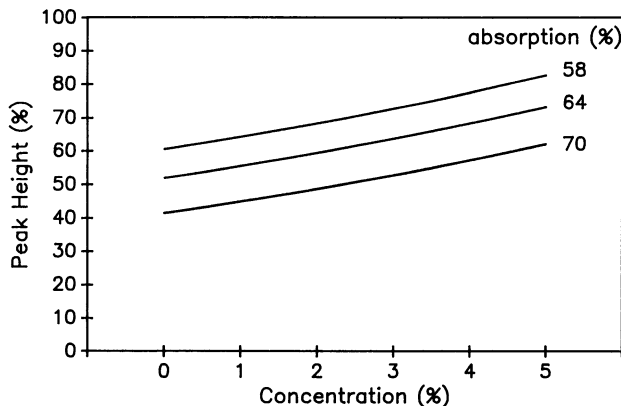


Fig. 4. Response surface method predicted mixogram peak height for vital gluten addition at different concentrations and for different absorptions. Multiple second-order regression,  $R = 0.99$ .

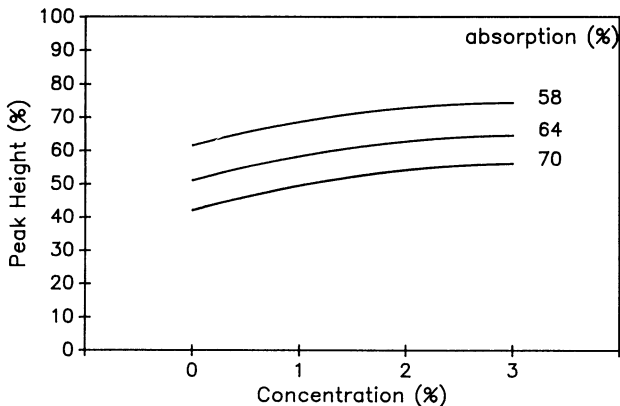


Fig. 5. Response surface method predicted mixogram peak height for addition of  $KIO_3$ , an oxidant, at different concentrations and for different absorptions. Multiple second-order regression,  $R = 0.99$ .

(work input) did decrease with an increase in concentration, however, due to the shortened mixing time.

## Surfactants

An increase in the time to peak occurred with an increase in SSL concentration (Fig. 7). This agrees with results by Watson and Walker (1986). There was no statistically significant effect on the peak height with increased SSL concentration, but the area under the curve (work) increased because of the longer mixing times. When SE F-160 was added to doughs, no major changes were found in the peak times or heights or, therefore, in the work input. These relatively stable mixing characteristics might be advantageous when choosing an emulsifier system.

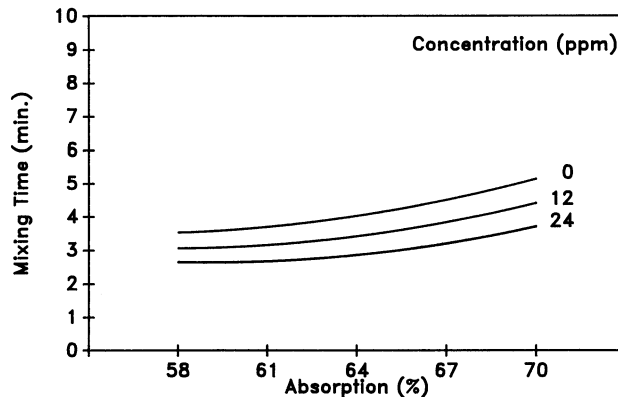


Fig. 6. Response surface method predicted change in mixogram mixing time (time to midline peak) for cysteine, a reductant, at different concentrations and for different absorptions. Multiple second-order regression,  $R = 0.99$ .

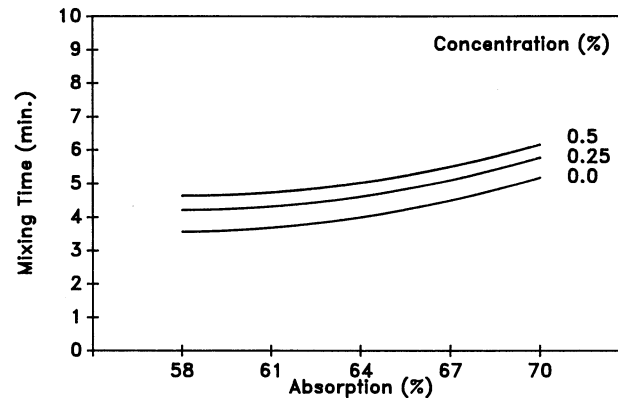


Fig. 7. Response surface method predicted change in mixogram mixing time (time to midline peak) for sodium stearyl lactylate, a surfactant, at different concentrations and for different absorptions. Multiple second-order regression,  $R = 0.98$ .

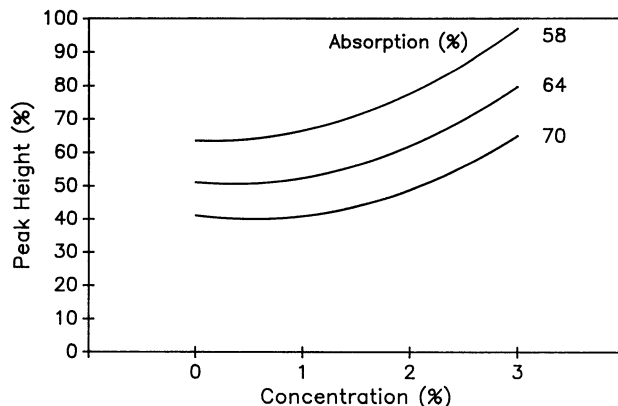


Fig. 8. Response surface method predicted change in mixogram midline peak height for  $MgSO_4$ , a salt, at different concentrations and for different absorptions. Multiple second-order regression,  $R = 0.98$ .

## Salts

With the exception of  $\text{CaCl}_2$ , all the added salts increased mixing time, the sulfates dramatically so at higher concentrations and absorptions.  $\text{CaCl}_2$  slightly decreased the mixing time required to peak with increased additions at higher absorptions.

Increased concentrations of  $\text{NaCl}$  and  $\text{KCl}$  both produced an increase in peak height. The 2.6%  $\text{KNO}_3$  decreased the peak height at low absorption (58%) but increased it at higher absorptions, when compared to the control (0%  $\text{KNO}_3$ ).  $\text{Na}_2\text{SO}_4$  increased peak heights at all concentrations, but  $\text{CaCl}_2$  addition had relatively little effect on peak heights. Figure 8 shows that when  $\text{MgSO}_4$  was added to the dough, however, a much larger increase in peak height occurred (about 30% of scale at each absorption), for 2.6%  $\text{MgSO}_4$  addition than for other salt. The increase, rather than decrease, indicates that the behavior of the sulfates was not due to residual traces of sulfites.

Increasing concentrations of  $\text{NaCl}$ ,  $\text{KCl}$ ,  $\text{Na}_2\text{SO}_4$ ,  $\text{KNO}_3$ , and  $\text{MgSO}_4$  all increased the area under the curve.  $\text{CaCl}_2$  gave very little change in area with increased concentrations.

## Other Additives

Barley malt did not have any effect on the mixing peak time. Malt addition gave a significant decrease in peak height at 0.2% but not at 0.5%. The reason for this contradictory behavior is not clear, but it might be caused by increased water absorption by damaged starch enzymolysis. The area under the curve likewise showed a slight decrease at the 0.2% level but increased at 0.5%, returning to a value close to that of the control and indicating a "tightening" of the dough.

Adding the preservative calcium propionate had no significant effect on the mixing time. However, peak height increased.

## CONCLUSIONS

Independent of the additive used, increasing water addition increased the mixing times and decreased peak heights. Increasing the concentrations of additives generally increased peak heights, but the changes in mixing times varied with the type of additive used.

Vital glutes increased mixing peak height and area under the curve (work to peak). Oxidants did not show a general pattern in how they affected dough mixing properties. The reductant

L-cysteine reduced mixing time but did not change peak height. Except for  $\text{CaCl}_2$ , all salts increased mixing time, although they did not all affect peak height in the same way.

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