Effects of Lactic Acid, Acetic Acid, and Table Salt on Fundamental Rheological Properties of Wheat Dough

K. WEHRLE,[1,2] H. GRAU,[1,2] and E. K. ARENDT[2,3]

ABSTRACT

The effects of the main metabolites, lactic and acetic acids, from the sourdough process on wheat doughs were tested with a dynamic sinusoidal oscillation test. Tests were done with a controlled stress rheometer. Dough treatment included four mixing times and four rest times before measurement. Phase angle, complex modulus, and viscosity were measured for all doughs at selected rest and mixing times, at frequencies ranging from 0.01–10 Hz. Results for all combinations of mixing and rest times were compared at 10 Hz. Effects of mixing time were most visible immediately after mixing and disappeared partially during rest time. Doughs that contained acid but no salt showed the clearest characteristics of overmixing, expressed by an increase in phase angle and decrease in complex modulus.

Cereal Chem. 74(6):739–744

Existing fundamental rheological measurements, such as the dynamic sinusoidal oscillation test, are excellent methods for describing the viscoelastic behavior of doughs (Weipert 1990). This information is useful for explaining basic processes and understanding the influence and interactions of many production parameters. Therefore, dough rheology was used to examine the influence of many different ingredients and process factors, determine flour quality, and predict baking quality.

Sourdough fermentation is an ancient bread-production process (the only method for bread leavening before the discovery of yeast in beer production [Röcken and Voysey 1995]). Acidification with sourdough is still necessary in rye breads or rye-wheat combination breads. In wheat bread production, sourdough has regained its importance because it is an easy way to improve taste and flavor (Brümmer and Lorenz 1991). The metabolism of microorganisms present in sourdough has been studied by a number of researchers (Martinez-Anaya et al 1990, Böcker 1993, Reinkemeier 1994, Stolz 1995). Metabolic compounds of sourdough microorganisms, mainly lactic acid bacteria, are dependent on the substrates provided. The addition of sourdough to wheat breads can lead to improved taste and shelf-life (Collar Esteve et al 1994).

The addition of sourdough during industrial bread production influences dough characteristics. The effects of sourdough on doughs are complex due to the wide variety of sourdoughs (e.g., type of starter cultures, dough yield, dough temperature, and additives). Incorporation of sourdough, especially the drop in pH value caused by the organic acids produced, influences the viscoelastic behavior of doughs. A correct description of the changes in dough behavior is necessary to maintain handling and machinability in industrialized production. Some earlier studies have examined the influence of acids and different pH values on dough properties. These studies were done with empirical rheological measurements, for example the farinograph (Maher Galal et al 1978). A strong interaction was found between salt and acid. Acids strongly influence the mixing behavior of doughs, and doughs with lower pH values require a slightly shorter mixing time and have less stability than normal doughs (Hoseney 1994). Also, a reduction in the extensibility of doughs with different acids was found (Bennett and Ewart 1962).

Flour enzymes also can be influenced by acids. The effects of acids on dough development and mixing tolerance are stronger for flour with higher enzyme activities (Harinder and Bains 1990). Fundamental rheological properties of wheat doughs after various mixing and rest times have been described by Kaufmann (1993). No information is available to date on the recovery behavior of doughs with acids during rest time. In this study, the influence of lactic and acetic acids on wheat doughs with and without added salt were studied with an oscillation test on a controlled stress rheometer. Mixing and rest times were varied.

MATERIALS AND METHODS

Ingredients

A commercial wheat flour without any additives (Odlum Group, Dublin) was used in the test series. Lactic acid (LA), acetic acid (AA), and table salt were analytically pure chemicals from British Drug House, Poole, England. Added water was deionized.

Farinogram and Acidity

Farinograms were performed according to International Association for Cereal Science and Technology standard method 115/1 at a mixing speed of 63 ± 2 rpm (ICC 1995). The standard method was modified by the addition of table salt and acids, which were solubilized in part of the total water at the beginning of the mixing period. Total titratable acidity and pH values were determined potentiometrically following the standard method (Arbeitsgemeinschaft Getreideforschung 1994).

Dough Mixing

Doughs for rheological measurement were prepared in a Glutomatic 2200 (Falling Number AB, Stockholm), which allowed constant and reproducible mixing of small quantities of dough. Mixing speed was 120 rpm. The Glutomatic normally is used to determine the gluten content according to ICC standard method 137 (ICC 1995). Normal addition of washing solution was stopped, and a special mixing chamber without a bottom perforation was used. Flour (10 g, 14% moisture) and solution (6 ml) were mixed for 0.5, 1, 3, 6, and 9 min. A mixing time of 1 min in the Glutomatic was identified as optimal for the doughs compared to doughs mixed in a farinograph for about 2 min. The differences in mixing times were due to the more intensive mixing procedure in the Glutomatic. The solutions contained, depending on the recipe, different concentrations of salt and lactic or acetic acid (Table I). After mixing, the doughs were gently removed from the mixing bowl and allowed to rest for 1, 12, 15, or 30 min. After resting,

[1]National Food Biotechnology Centre, University College, Cork, Ireland.
[2]Department of Food Technology, University College, Cork, Ireland.
[3]Corresponding author. Phone: +353-21-902064. Fax: +353-21-276318. E-mail: e.arendt@ucc.ie.

Publication no. C-1997-1027-02R.

the doughs were placed between the rheometer plates, the gap was adjusted, and the whole system was covered. Water-saturated cotton strips were placed on the inner side of the cover to create an atmosphere with high relative humidity. Therefore, no drying out of the dough rim occurred during the tests. The oscillation tests began after 1 min for the doughs with 1- and 12-min rest times and after 15 min for the doughs with 15- and 30-min rest times. The total rest times of the doughs were 2, 13, 30, and 55 min.

Rheological Measurements

Rheological measurements were performed on a Bohlin controlled stress rheometer (Bohlin Rheology AB, Lund, Sweden). The geometry used was parallel plates with a 40-mm diameter and 2-mm gap. In a strain sweep test (data not shown), the linear region for these doughs was $<6 \times 10^{-4}$ strain; therefore, oscillation measurements were done at 6×10^{-4} strain. Oscillation frequencies ranged from 0.01–10 Hz. Sixteen measuring points were recorded. The Bohlin software package was used to calculate complex modulus (G^*), phase angle (δ), and viscosity (η'). In the figures, the complex parameter G^* is expressed as a modulus ($|G^*|$). Every result is at least the average of three measurements. Analysis of variance was performed to identify significant differences between means.

RESULTS AND DISCUSSION

Influence of Salt and Acids on Farinograms

Variation in pH value (Table II) caused by addition of LA changed the mixing behavior of doughs drastically. Fig. 1 shows the farinograms of doughs with different additives. The doughs were standardized to 60% water absorption. The corresponding parameters of these farinograms are listed in Table III. The development times of these doughs differed only slightly; addition of acids resulted in shorter development times. Larger differences were observed for the resulting dough consistencies. Doughs with LA and salt had maximum consistencies of 440 BU, whereas doughs without additives had values of 600 BU, despite a water absorption of 60% for all doughs. Also, large differences were found in the degree of softening, especially after 20 min. Addition of salt led to softer doughs with more stability, whereas addition of acids resulted in firmer doughs with less stability. Doughs containing LA but no salt showed a second maximum in consistency after 9 min and softened very quickly after that point. This indicated major changes in dough structure, mainly in protein structure, which was caused by acids (Maher Galal et al 1978). The overall shapes of the farinograms expressed the extreme influence of acids combined with salt on the mixing behavior of dough better than the values for development time, stability, and degree of softening (Fig. 1).

Effects of Acids and Salt on the Fundamental Rheology of Optimally Mixed Doughs After Relaxation

All doughs over different frequencies showed the same trend for the rheological parameters phase angle (δ), complex modulus (G^*), and viscosity (η'). Phase angles showed minimum values for all doughs at frequencies between 0.1 and 1 Hz (Fig. 2). Phase angles were higher at lower frequencies, whereas they increased only slightly at higher frequencies. Addition of acids did not change this behavior over increasing frequencies. Doughs without additives resulted in the highest phase angles at most frequencies, followed by doughs with 2% salt. Doughs with 2% salt and either 0.5% LA, 0.3% AA, or 0.7% AA had nearly equal phase angles, especially at frequencies >1 Hz. Doughs with 2% salt and 1% LA showed significantly lower phase angles, whereas doughs with 1% LA and no added salt generated the lowest phase angles. LA showed a greater effect on phase angles than AA at the same molar concentrations. This can be explained by the different pH values of the doughs, which were due to differences in the strengths of the acids (Table II). Addition of 1% LA led to pH values that were 0.5 lower than for 0.7% AA, and acidities were slightly different despite equal molar concentrations of 0.11 mol acid/100 g of flour. Addition of acids led to doughs with more elastic behavior at optimal mixing conditions and after some rest time. Addition of salt to doughs with LA produced only minor effects on viscoelastic behavior under these conditions.

Complex modulus (G^*) increased with increasing frequency, and the curves for all combinations had nearly the same slope (Fig. 3). There were no significant differences in G^* for doughs without acids. Doughs with 2% salt and either 0.5% LA, 0.3% AA, or 0.7% AA resulted in the same levels of G^*. Doughs with 1% LA led at all frequencies to the highest G^* values. Among these three groups, there were significant differences in G^* at all frequencies. Higher values for G^* indicated that the dough was firmer. A decrease in phase angle and increase in G^* due to the addition of acids indicated that the dough was more elastic and became simultaneously firmer.

Viscosity η' is a third rheological parameter that describes dough consistency. Results for viscosity over frequency showed typical shear thinning of doughs (Fig. 4). The slopes were similar for all

TABLE I
Dough Recipes[a]

No.	Name	Added Salt (%)	Added LA[b] (%)	Added AA[b] (%)
1	Basic	…	…	…
2	2s	2	…	…
3	2s, 0.5LA	2	0.5	…
4	2s, 1LA	2	1.0	…
5	2s, 0.3AA	2	…	0.33
6	2s, 0.7AA	2	…	0.67
7	1LA	…	1.0	…

[a] All percents based on flour (14% moisture).
[b] LA = lactic acid and AA = acetic acid.

TABLE II
pH Values and Total Titratable Acidities (TTA) of Doughs

No.	Name[a]	pH	TTA (mL)
1	Basic	6.3	1.7
2	2s	6.4	1.7
3	2s, 0.5LA	4.7	4.1
4	2s, 1LA	4.0	6.2
5	2s, 0.3AA	5.0	4.4
6	2s, 0.7AA	4.5	7.3
7	1LA	4.0	6.3

[a] LA = lactic acid and AA = acetic acid.

TABLE III
Results of Farinograms with 60% Water Absorption

No.	Name[a]	Maximum Viscosity (BU)	Development Time (min)	Stability (min)	Degree of Softening (BU) 12 min	Degree of Softening (BU) 20 min
1	Basic	600	1.9	3.0	85	115
2	2s	500	2.3	15.5	30	40
4	2s, 1LA	440	1.5	1.4	80	70
7	1LA	550	2.0	2.0	105	210

[a] LA = lactic acid.

doughs. Dough with 1% LA showed the highest viscosity. The lowest viscosities at all frequencies were achieved in doughs without acids. Changes in mixing and rest times significantly influenced the results of rheological measurements of dough. Changes in complex modulus, phase angle, and viscosity with mixing and rest times always pointed in the same direction and mainly had the same levels over all frequencies.

Effect of Mixing Time at 10 Hz

Complex modulus, phase angle, and viscosity of various doughs produced larger differences after short rest times. After longer rest times, doughs with different mixing times became similar but normally did not achieve the same values. During rest time, the values for these rheological terms also differed. The directions of the changes depended on mixing times. Doughs with average mixing times of 1 and 3 min did not change as much with longer rest times as did the under- and overmixed doughs. When measured 2 min after mixing, the phase angle for all doughs significantly increased as mixing times increased (Fig. 5). During mixing, doughs developed a more viscous response. The lowest increase in phase angle was achieved with doughs that contained salt but no acid. An increase in mixing time had the greatest effect on dough prepared with 1% LA but no salt. After mixing times of 0.5 and 1 min, these doughs had the lowest phase angles, whereas after longer mixing times, 3, 6, and 9 min, the phase angles were much higher than for all other doughs. This indicated a sudden breakdown of these doughs caused by overmixing.

When mixing time was increased, G^* decreased after a 2-min rest. Doughs became softer during mixing (Fig. 6), and doughs with

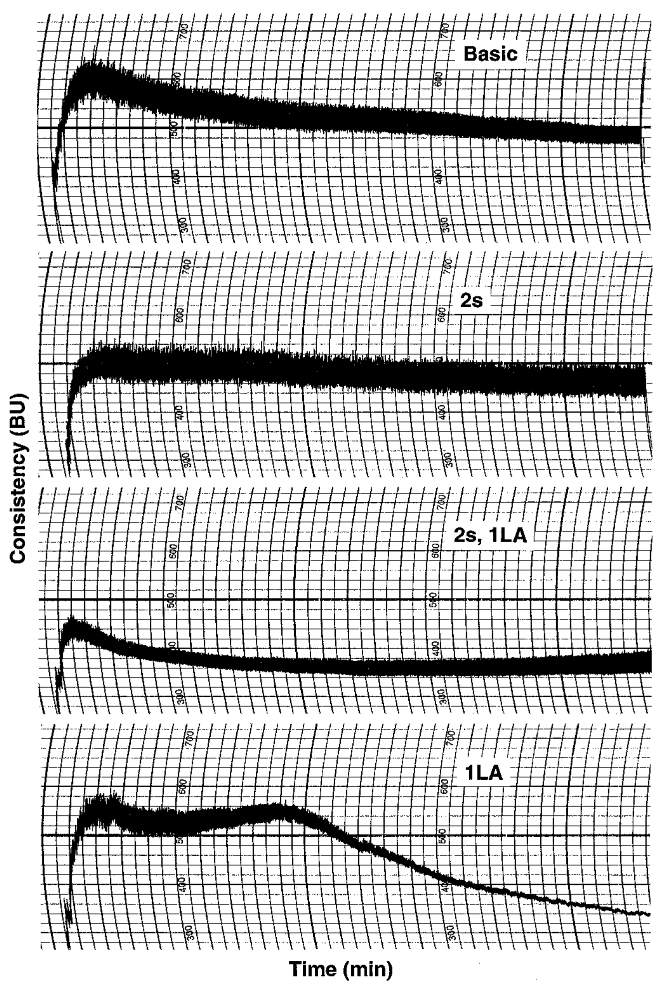

Fig. 1. Farinograms of wheat dough recipes with various amounts of acids and table salt (water absorption 60%).

1% LA showed a drastic decrease in G^* between short mixing times and mixing times ≥3 min. The viscosity of the doughs showed similar results, particularly for doughs with 1% LA and no salt (Fig. 7). These fundamental rheological measurement results confirmed the results of the empirical rheological measurements with the farinograph. The doughs showed a comparable sudden breakdown in dough consistency after a mixing time of 9 min in the farinograph mixer.

Effects of Rest Time at 10 Hz

The rheological condition of doughs changed completely after longer rest times. The influence of mixing time on all rheological terms was quite contrary for doughs without acids after rest times of 3 min and longer. Phase angles of doughs with short mixing times were higher than those of overmixed doughs after longer rest times, except for doughs with LA (Fig. 5). Phase angles of

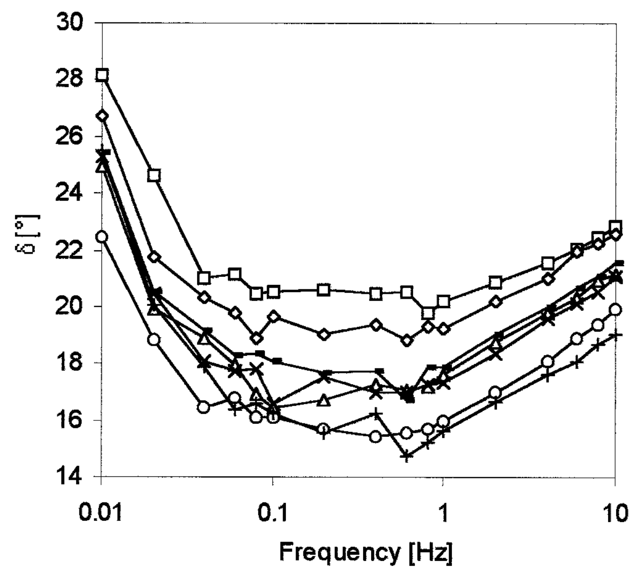

Fig. 2. Phase angle (δ) as a function of frequency for wheat doughs with various amounts of acids and table salt (mixing time 1 min, rest time 30 min). Recipe: □ basic; ◇ 2s; △ 2s, 0.5 LA; ○ 2s, 1LA; ━ 2s, 0.3 AA; × 2s, 0.7AA; and + 1LA.

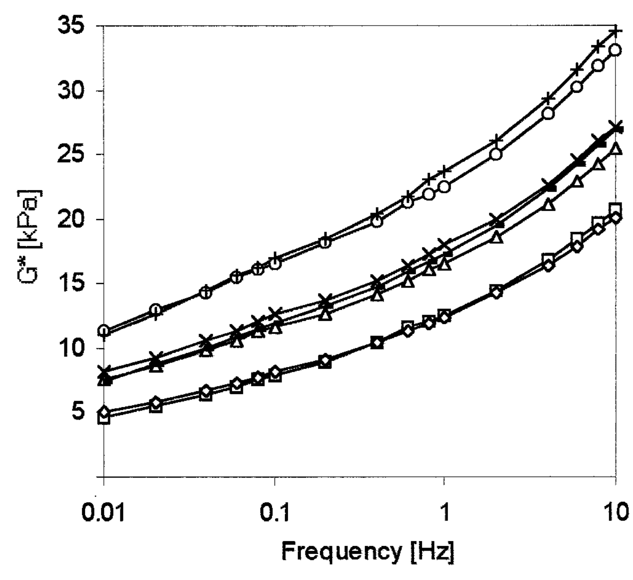

Fig. 3. Complex modulus (G^*) as a function of frequency for wheat doughs with various amounts of acids and table salt (mixing time 1 min, rest time 30 min). Recipe: □ basic; ◇ 2s; △ 2s; 0.5 LA; ○ 2s, 1LA; ━ 2s, 0.3 AA; × 2s, 0.7AA; and + 1LA.

undermixed doughs increased during rest times, whereas phase angles of overmixed doughs decreased. A combination of a mixing time of 0.5 min and a rest time of 55 min produced doughs (no acid added) with phase angles as high as those mixed for 9 min and rested for 2 min. The lowest phase angles were obtained with mixing for 9 min and resting for 55 min. Phase angles resulting for doughs without any additives dropped drastically over rest time when mixed for longer than 3 min, whereas in doughs with 2% salt the decrease in phase angle over rest time was largest with mixing times between 6 and 9 min. Under- and optimally mixed doughs relaxed during rest time and became more viscous, which was illustrated by an increase in phase angles, whereas overmixed doughs became less viscous during rest. Doughs that contained salt alternated between increases and decreases in phase angles over rest times after longer mixing times compared to doughs without salt.

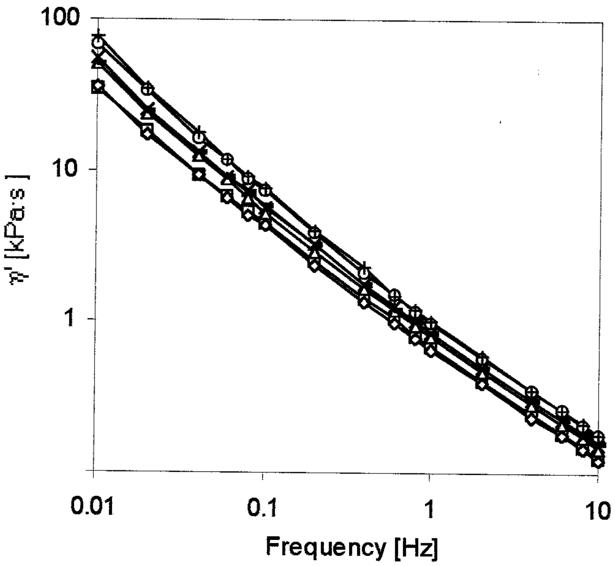

Fig. 4. Viscosity (η′) as a function of frequency for wheat doughs with various amounts of acids and table salt (mixing time 1 min, rest time 30 min). Recipe: □ basic; ◇ 2s; △ 2s, 0.5 LA; ○ 2s, 1LA; ▬ 2s, 0.3 AA; × 2s, 0.7AA; and + 1LA.

The phase angle for doughs with 1% LA and 0.7% AA did not change as much over rest time. There was a decrease in phase angle with longer rest times after 6 and 9 min of mixing but no increase after shorter mixing times. Mixing times only influenced the phase angles of these doughs a little after rest times of 55 min.

A large difference in phase angle values occurred independent of rest time for doughs with 1% LA between 1 and 3 min of mixing. Phase angles of overmixed doughs decreased over longer rest times, and phase angles of undermixed doughs increased with longer rest times. After maximum rest times, phase angles for shorter mixing times were still much smaller than for longer mixing times. The lowest phase angles were observed with short mixing and rest times. The highest phase angles were observed for long mixing and short rest times.

Complex modulus showed a development opposite that of the phase angle over all mixing and rest times (Fig. 6). Complex modulus decreased over rest time after 0.5 and 1 min of mixing and increased over rest time after 6 and 9 min of mixing. Doughs without acids weakened after short mixing times over rest time, whereas overmixed doughs became firmer during rest periods. As a result, overmixed doughs were firmer after longer rest periods than undermixed doughs. Doughs containing acids and salt also changed over rest time. The results of these changes were nearly equal for the complex modulus for doughs with different mixing times after a 55 min rest. The damage to dough structure in the doughs with LA was so immense that even after longer rest times overmixed doughs were much weaker than optimally mixed doughs.

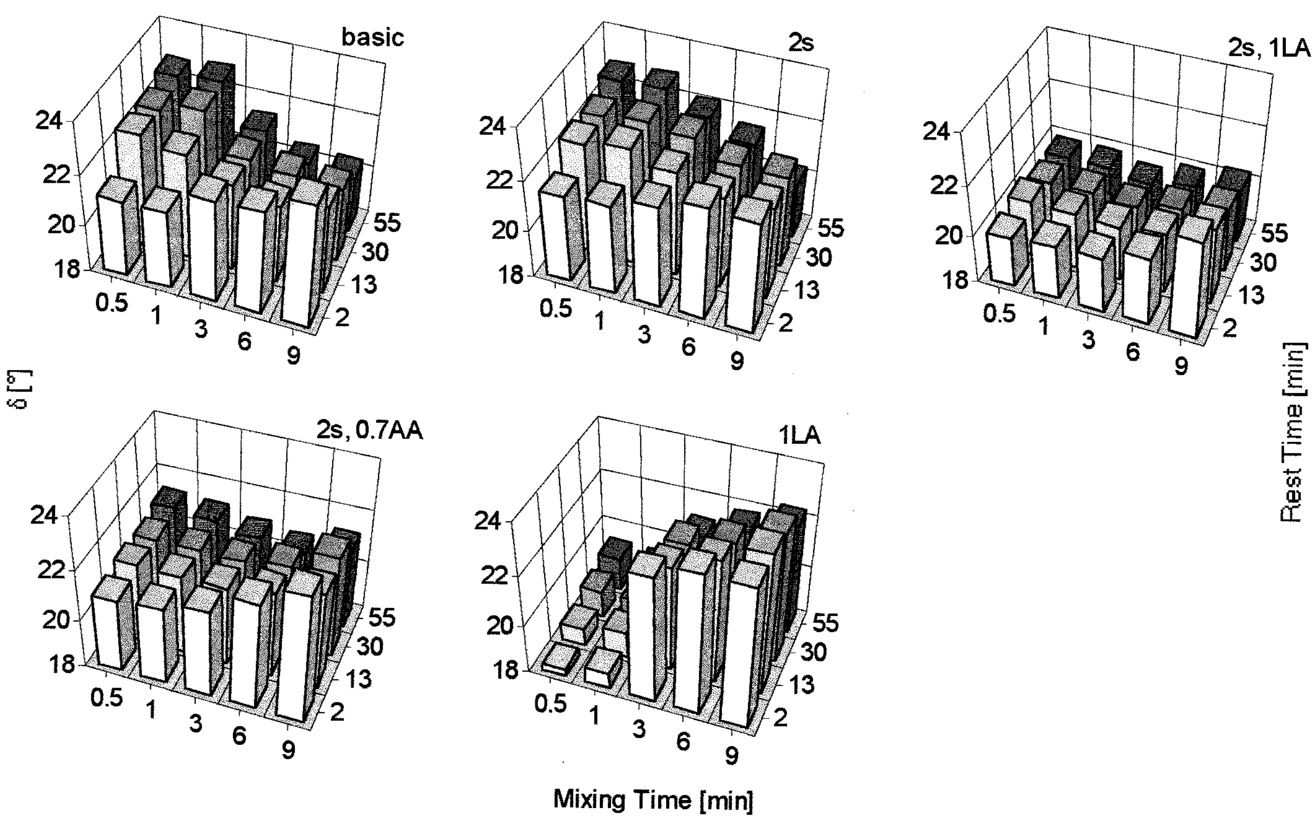

Fig. 5. Effects of rest and mixing times on the phase angle (δ) for dough recipes with various amounts of acids and table salt (frequency 10 Hz).

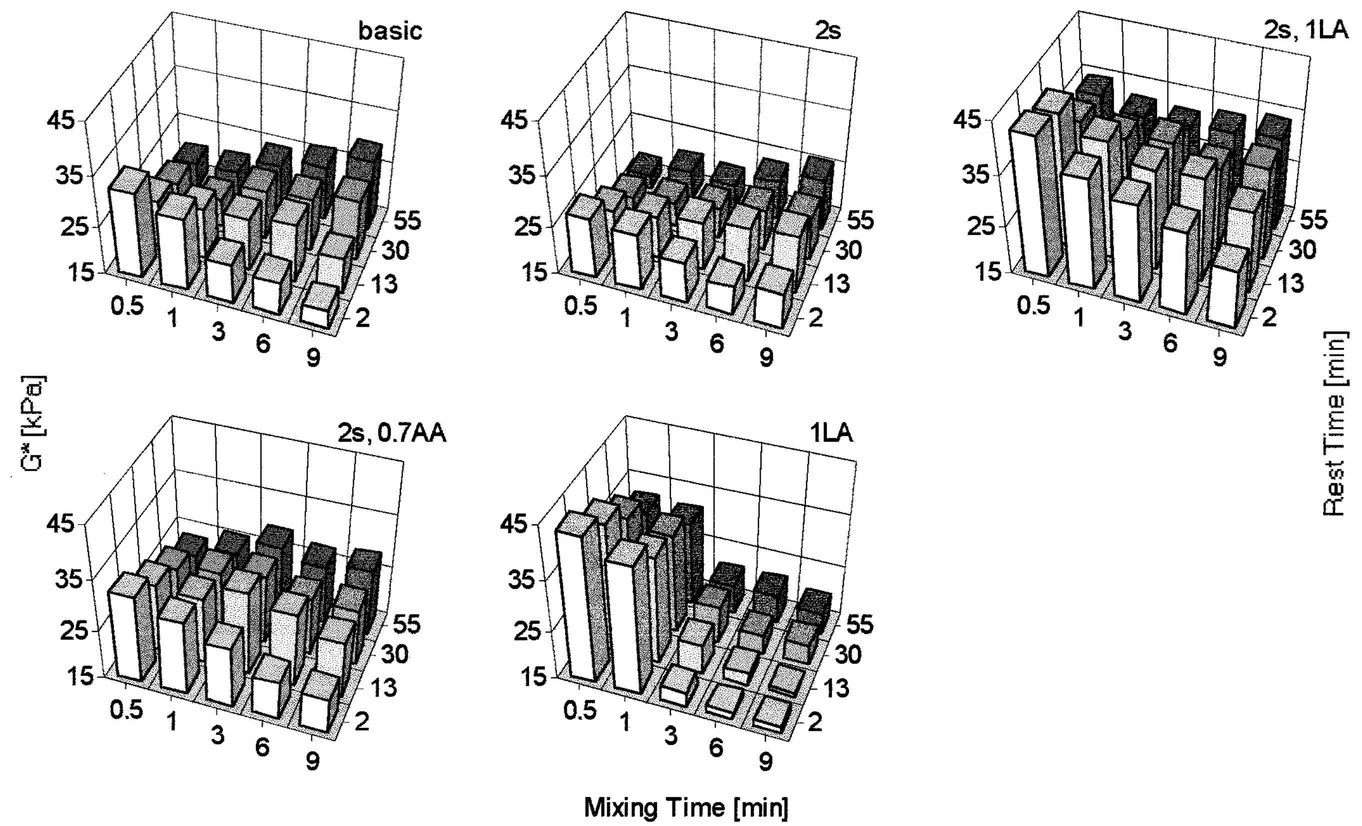

Fig. 6. Effects of rest and mixing times on the complex modulus (G^*) for dough recipes with various amounts of acids and table salt (frequency 10 Hz).

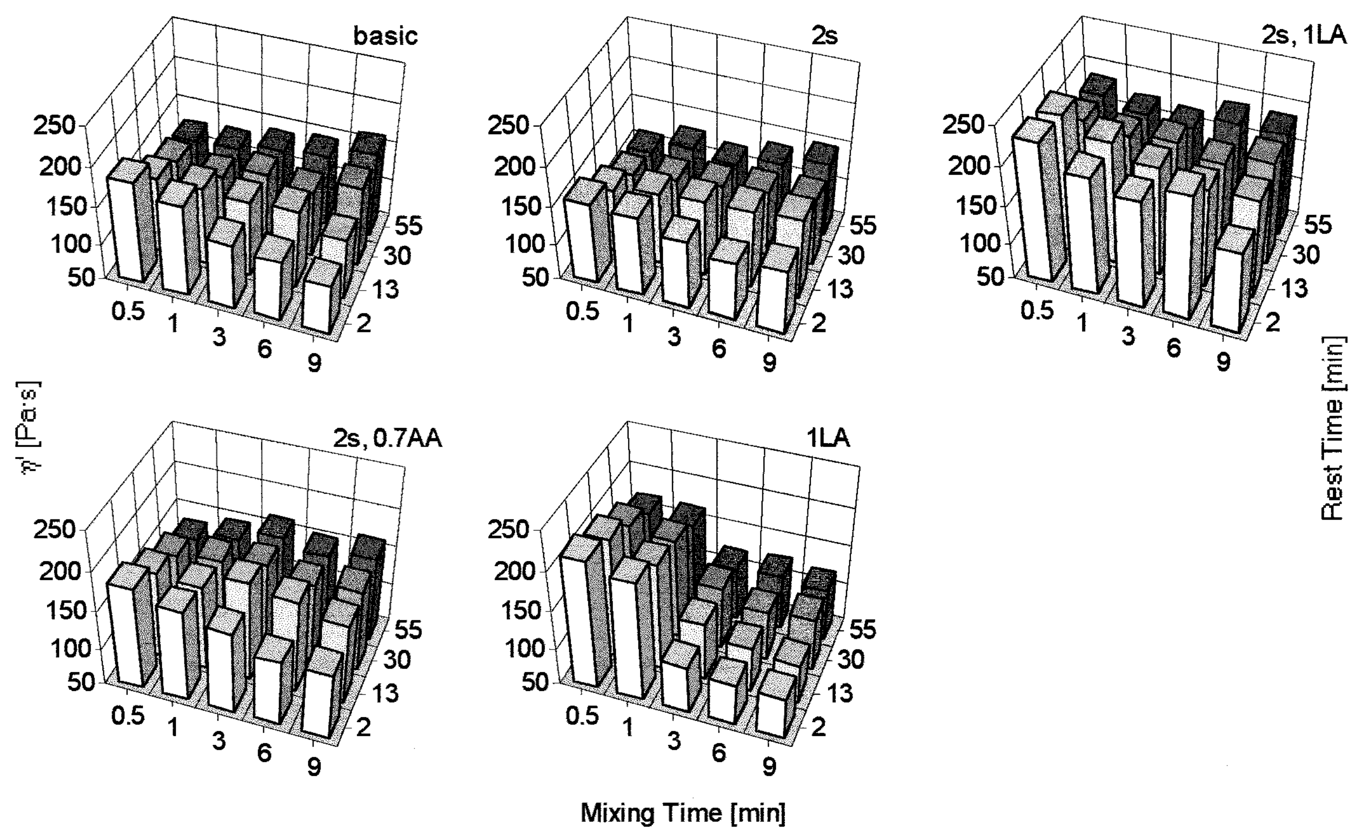

Fig. 7. Effects of rest and mixing times on the viscosity (η') for dough recipes with various amounts of acids and table salt (frequency 10 Hz).

Comparisons of doughs with different recipes after short mixing times showed the lowest phase angles at all rest times for doughs with LA followed by doughs with AA. Doughs without acids had the highest values for phase angle. Doughs with acids contained more elastic components after short mixing times. Longer mixing times resulted in higher phase angles for doughs with LA and without salt than for all other doughs at all mixing times. The range in phase angle for all other doughs after longer mixing times depended on rest times and the ability of the doughs to recover from overmixing. Over all mixing and rest times, doughs with LA and salt had higher G^* values than all other doughs. Doughs with LA but without salt achieved nearly the same high values after short mixing times, but the G^* values for these doughs dropped to the lowest levels after overmixing.

Influence of Rest Time on Short Mixed Doughs at Different Frequencies

For all frequencies, doughs without acids had the same ranking and nearly the same relative difference between all rheological parameters, whereas doughs with acid tended to show bigger differences in phase angle for different rest times at lower frequencies (Fig. 8). For doughs with LA, phase angle values at frequencies >1 Hz were nearly the same for all rest times. At frequencies <1 Hz, the phase angles for doughs after shorter rest times increased much more compared to doughs after longer rest times. Undermixed doughs with acids at low frequencies were more viscous immediately after mixing than after long recovery times. Further tests should reveal whether this behavior leads to different flow behavior of these doughs during storage.

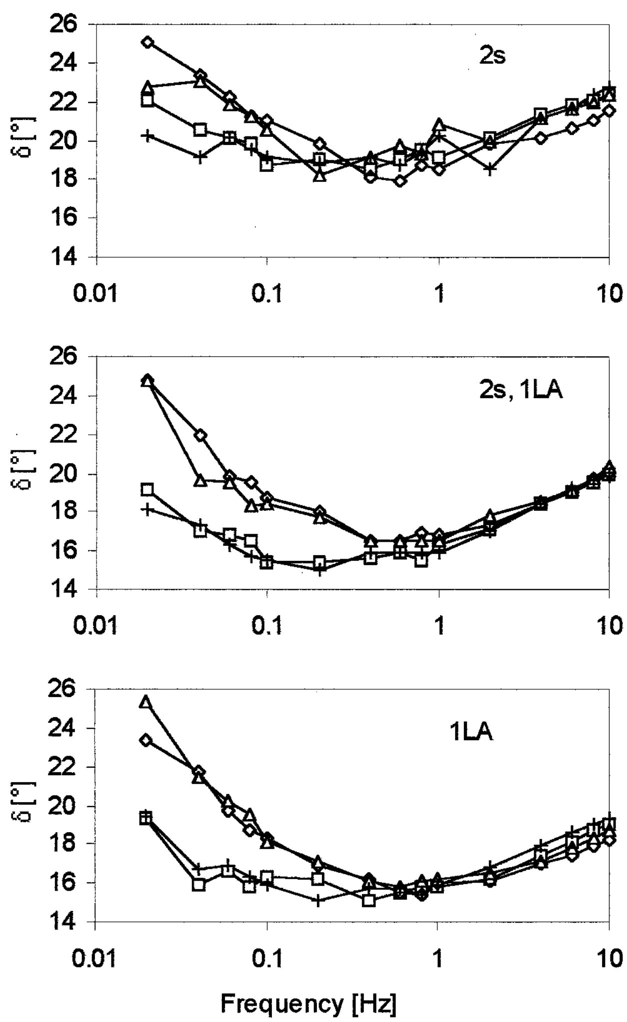

Fig. 8. Phase angle (δ) as a function of frequency for undermixed dough recipes (mixing time 0.5 min) with various amounts of acids and table salt after varying rest times: ◇ 2 min; △ 13 min; □ 30 min; and + 55 min).

CONCLUSIONS

Doughs with acids initially were firmer and more viscous than doughs without acids but showed less stability during mixing. Addition of acids intensified the decrease in G^* and increase in δ with longer mixing times when measured immediately after mixing, producing weaker and more viscous overmixed doughs than when doughs without acids were overmixed. Doughs containing acids without salt showed greater sensitivity to overmixing. Salt strengthened dough structure and reduced the effects of overmixing. Addition of acids also strengthened the dough structure at the beginning of the mixing phase but caused opposite effects after longer mixing times. There was no unique trend in changes caused by acids in combination with salt, because of interactions between recipe, mixing time, and rest time and their effects on rheological dough behavior.

ACKNOWLEDGMENTS

This research has funded in part by grant aid under the food sub-programme of the operational programme for industrial development, administered by the Department of Agriculture, Food, and Forestry and was supported by national and EU funds. We thank S. Gräber from the University of Hohenheim, Germany, for critical reading.

LITERATURE CITED

Arbeitsgemeinschaft Getreideforschung e.V. 1994. Standard Methoden für Getreide Mehl und Brot, 7th ed. Verlag Moritz Schäfer: Detmold, Germany.

Bennett, R., and Ewart, J. A. D. 1962. The reaction of acids with dough proteins. J. Sci. Food Agric. 13:15-23.

Böcker, G. 1993. Ökologische und physiologische Charakterisierung der sauerteigtypischen Stämme *Lactobacillus sanfrancisco* und *Lactobacillus pontis* sp. nov. PhD dissertation. Institut für Lebensmitteltechnologie, Universität Hohenheim: Hohenheim, Germany.

Brümmer, J.-M., and Lorenz, K. 1991. European developments in wheat sourdoughs. Cereal Foods World 36:310-314.

Collar Esteve, C., Benedito de Barber, C., and Martinez-Anaya, M. A. 1994. Microbial sour doughs influence acidification properties and breadmaking potential of wheat dough. J. Food Sci. 59:629-633.

Harinder, K., and Bains, G. S. 1990. High α-amylase flours: Effect of pH, acid, and salt on the rheological properties of dough. Cereal Chem. 67:588-594.

Hoseney, C. 1994. Yeast leavened products. Pages 229-272 in: Principles of Cereals Science and Technology, 2nd ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

ICC. 1995. Standard Methods of the International Association for Cereal Science and Technology. The Association: Vienna.

Kaufmann, B. 1993. Rheologische Eigenschaften von Weizenteigen. PhD dissertation. Institut für Lebensmitteltechnologie, Universität Hohenheim: Hohenheim, Germany.

Maher Galal, A., Varriano-Marston, E., and Johnson, J. A. 1978. Rheological dough properties as affected by organic acids and salt. Cereal Chem. 55:683-691.

Martinez-Anaya, M. A., Pitarch, B., Bayarri, P., and Benedito de Barber, C. 1990. Microflora of the sourdoughs of wheat flour bread. X. Interactions between yeasts and lactic acid bacteria in wheat doughs and their effects on bread quality. Cereal Chem. 67:85-91.

Reinkemeier, M. 1994. Einsatz definierter Starterkulturen zur Herstellung von Weizensauerteigbroten. PhD dissertation. Fachbereich der Ernährungs- und Haushaltswissenschaften, Universität Gießen: Gießen, Germany.

Röcken, W., and Voysey, P. A. 1995. Sour-dough fermentation in bread making. J. Appl. Bacteriol. Symp. Suppl. 79:38-48.

Stolz, P. 1995. Untersuchungendes Maltosemetabolismus aus Sauerteig. PhD dissertation. Institut für Lebensmitteltechnologie, Universität Hohenheim: Hohenheim, Germany.

Weipert, D. 1990. The benefits of basic rheometry in studying dough rheology. Cereal Chem. 67:311-317.

[Received February 24, 1997. Accepted July 29, 1997.]