QUALITY WHEAT CRC PROJECT REPORT

Program 3: Processing Wheat & Wheat Products

Application of Ultrasound to Dough Processing

- Experimental Results

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1. EXECUTIVE SUMMARY

This report arises from the Quality Wheat CRC project 'Application of Ultrasound to Dough Processing'. This project was to investigate the application of ultrasound to dough processing, particularly at the mixing stage and to determine the likely success of longer term research into this technology.

- Bread dough strongly attenuates ultrasound, and unevenly applies sound waves through a proving bread dough. This results in significant temperature gradients throughout the dough.

- There were no significant changes in mechanical dough development (MDD) mixing requirement as a result of ultrasound treatment of dough after a short pre-mix, and there were no significant effects on loaf quality.

- Application of ultrasound through the base of a small batch mixer (125g flour capacity) was not successful. Like the ultrasound bath treatments, attenuation of the ultrasound, by the viscous dough, was the problem.

- After applying ultrasound to 25% flour-water slurries (sponge method), and then mixing the remaining flour and ingredients, the MDD mixing curves were flatter and longer. However, there was no measurable change in MDD work input to peak when all ingredients were used.

- For lean dough recipes, loaves that were baked showed a small increase in volume after the ultrasound treatment of the flour-water slurries. The occasional loaf also showed a finer crumb texture. However, when the full recipe was used, the volumes were lower than the non-treated controls.

- Overall, the improvements from treating flour-water slurries were small, may depend on the dough formula and currently do not seem to be worth the effort of using the ultrasound. The applications of ultrasound to the industry, especially in batch processes, would appear to be limited. Sponge and dough processes, where a flour-water slurry could be treated with ultrasound, are not used to any great extent in Australia or New Zealand.

- If used in conjunction with lower levels of ascorbic acid, the savings in ascorbic acid use and the product quality benefits from ultrasound treatment of slurries would have to offset the capital expense of setting up sonication systems in bakeries. It is still yet to be seen whether ultrasound can be used successfully on batch-mixed bread doughs.

It is our recommendation that this project will not be continued.

2. INTRODUCTION

This report is a record of experimental results and conclusions arising from the Quality Wheat CRC project 'Application of Ultrasound to Dough Processing'. This was a new project to investigate the application of ultrasound to dough processing, particularly at the mixing stage. The work was to involve a six month experimental investigation to determine the likely success of longer term research into this technology.

The first report from this project (Mackay, 1998) comprised a literature review of existing uses of ultrasound in the food processing industry and an assessment of the potential applications to dough processing using different ultrasonic techniques.

Ultrasound has a number of applications in the food industry ranging from measurement techniques using low intensity, high frequency sound waves, to techniques which effect permanent chemical change using high intensity, low frequency sound waves. The changes brought about by this second group are generally attributed to the effects of cavitation, the rapid growth and collapse of bubbles.

Use of ultrasound on bread dough has been recorded, however the application was for the continuous mixing process and used an ultrasonic whistle, a technique which was not available to researchers in this QWCRC project. The benefits that resulted from this treatment included reduced mixing requirement (Jackel, 1970). Another application used ultrasound to relax rolled pastry products (Walter, 1990).

Our experimental work was approached in two phases. Firstly, we used ultrasonic cleaning baths to treat bread dough by sonicating the dough either after a short pre-mix or after completion of mixing. Indeed, the most convenient time to treat the dough in a sonicating bath is after mixing, and prior to moulding, when the bread normally has a ten minute rest period. However, as this phase of experiments showed that bread dough strongly attenuates ultrasound, and unevenly applies sound waves through a proving bread dough, the second phase of experiments looked at ways of applying the ultrasound during the mixing process, using an ultrasonic probe.

3. METHODS AND EQUIPMENT

3.1 Ultrasound Generators

Two ultrasound baths and a probe were used in these experiments:

Unisonics K42-752 Ultrasonic Cleaner - for use with doughs mixed on the 125g MDD mixer

Power Supply	240 V, 40 W
Volume	250 ml
Operating Frequency	50 kHz

Unisonics FX10 Ultrasonic Cleaner - for use with doughs mixed on the twin Z-arm BP Mixer

Power Supply	240 V, 0.3 amps
Volume	3 litres
Operating Frequency	40 kHz

Branson Sonifier 250

The standard horn we use on this sonifier for HPLC work is a Double Stepped Micro tip, which operates at a very high intensity but is only suited to treating volumes of 250-500 μl. Therefore we purchased a Standard Disruptor horn that can deal with volumes of 10-250 ml. The Branson Sonifier 250 operates at a frequency of 20 kHz and has variable output control, which controls the intensity of ultrasonic activity by varying the amplitude of the waves.

3.2 Temperature Measurement

A multi-channel recorder, Smartreader Plus, was kindly lent to us by John Kalitsis and Thomas Adamczak at BRI Australia Ltd. This was fitted with 7 thermocouples for the measurement of temperature distribution in doughs.

3.3 Laboratory Mixers

For the mixing studies outlined in this report, two types of laboratory mixer were used.

The variable speed 125g MDD mixer is based on the small scale mechanical dough development (MDD) mixers described by Mitchell (1984, 1989). This mixer has a capacity of 125 g of flour. At 150 rpm typical dough development times are about 2 minutes.

The mixing action of this mixer is based on a twin-blade design - see Mitchell (1971).

The 125g mixer records mixing torque and work input is calculated in watt-hours per kg by

integrating the torque over the period of the mixing cycle (Mitchell 1989).

The second mixer used in this study was a variable speed 1kg Baker Perkins (BP) twin Z-arm mixer (Larsen & Greenwood 1991), that has a similar mixing configuration to the Morton twin Z-arm mixer. Doughs from this mixer are scaled to about 800g for baking commercial size loaves.

For both types of laboratory mixer, mixing, dough make-up and baking have been previously described (Larsen & Greenwood 1991).

3.4 Bread Crumb Measurements

Bread crumb properties were measured on the Textron or Instron using the Perspex sample assembly described by Morgenstern et al. (1995). For each loaf, middle slices were individually measured and the results averaged.

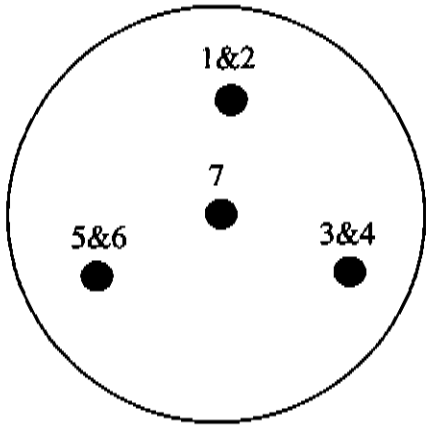
The probe used to pierce the slice of bread had a flat, circular leading edge of 25 mm diameter and was driven downwards through the sample at 100 mm/min. Analysis of the data (ASYST) gave values for crumb strength (Fmax (N)), the maximum force resisting the probe at the point of rupture.

4. APPLICATION OF ULTRASOUND USING AN ULTRASONIC BATH

4.1 Temperature Variation in the K42 Ultrasound Bath

Plain yeasted bread dough was prepared using the 125g mixer. The dough was placed in the K42 (small) ultrasound bath for treatment and seven thermocouples were placed at varying depths in the dough. Temperature readings were taken using Smartreader Plus to assess any variation in temperature occurring as a result of attenuation of ultrasound.

A perspex lid with drilled holes was used to support the thermocouples in a vertical position and to maintain the desired depth. The arrangement of the thermocouples is shown below.



In the first test, thermocouples 1, 3, 6 and 7 were placed at a depth of 3.5 cm from the top of the bath. Thermocouples 2, 4 and 5 were placed at a depth of 2.5 cm from the top of the bath. In the second test, 1 and 7 were placed 4.5 cm from the top, which is effectively the base of the bath, thermocouples 2, 3 and 6 were placed 3.5 cm from the top and 4 and 5 were placed 2.5 cm from the top.

4.1.1 Results

The results of these tests are presented graphically on the following page(Figure 1). They show that the temperature varies vertically by approximately 3°C/cm after 10 minutes of ultrasound treatment in this bath. That is, the dough that has been subjected to ultrasound treatment, even though the dough is quite small, does not have an even temperature distribution. This reflects the high attenuation of ultrasound in bread dough as sound waves are converted into thermal energy.

The increased variation in temperature at approximately 15 minutes in this experiment was due to the bread dough reaching the top of the bath. This resulted in displacement of the lid and the thermocouples were no longer at a fixed distance from the base of the bath.

Figure 1. **Dough Temperature Variation with Depth in the K42 Ultrasound Bath**

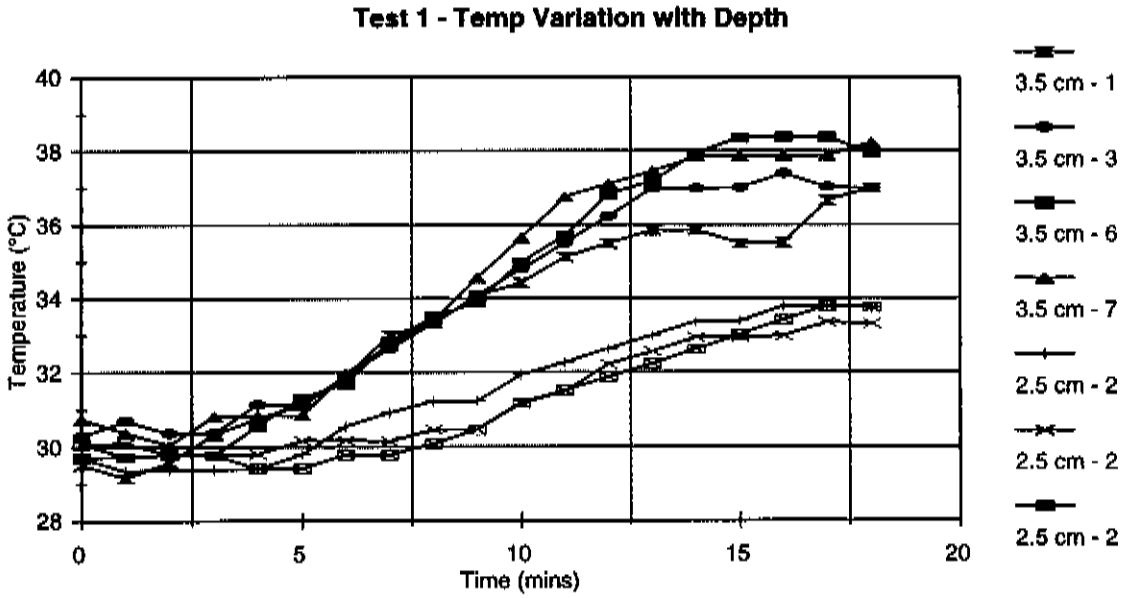
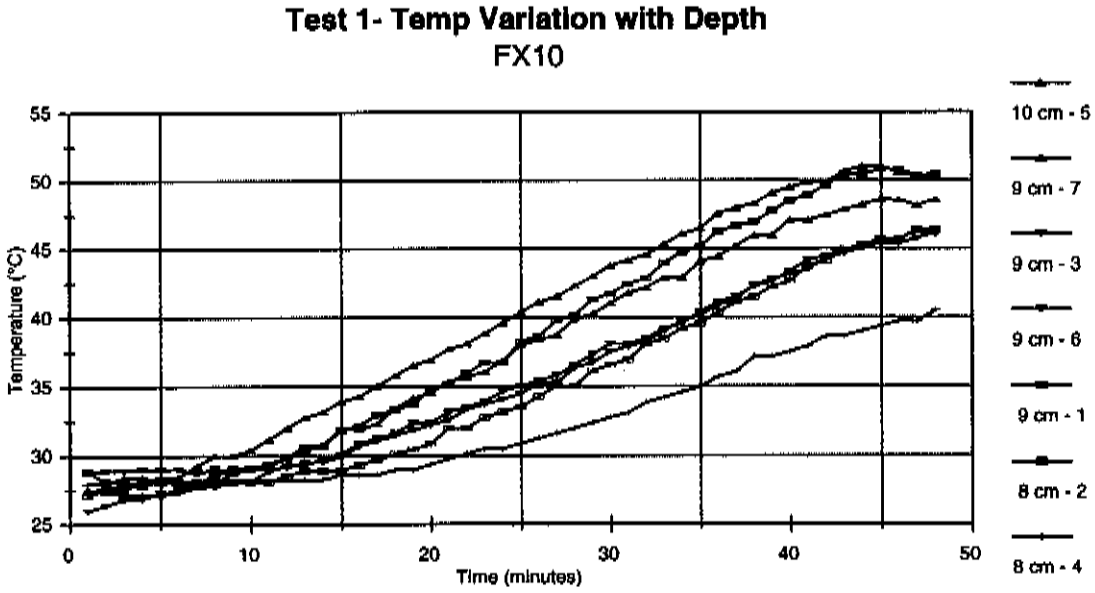
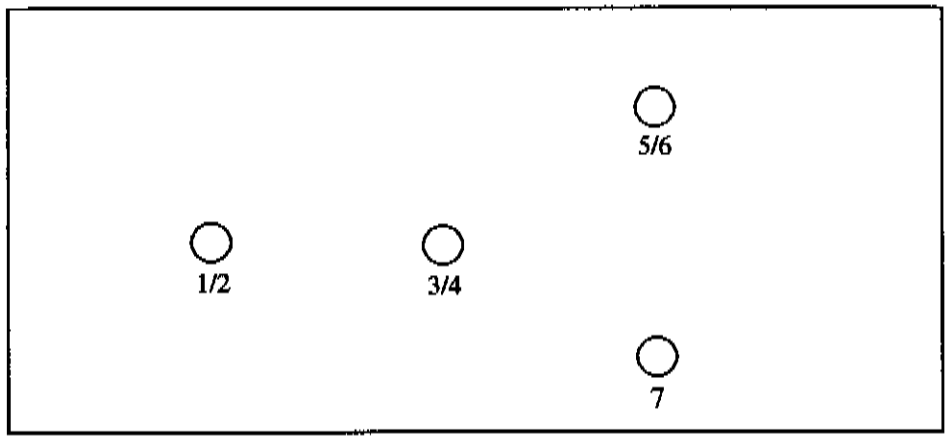


Figure 2. **Dough Temperature Variation with Depth in the FX10 Ultrasound Bath**



4.2 Temperature Variation in the FX10 Ultrasound Bath

A similar procedure was followed as outlined for the K42 bath. However, dough was prepared in the twin Z-arm BP mixer (1kg flour) and half the dough (800 g) was placed in the bath.



To measure the temperature gradients due to ultrasound treatment, the thermocouples were supported by a perspex lid and placed in the dough at the following depths:

Thermocouple 5 was placed at 10cm. Thermocouples 1, 3, 7, 6 were placed at 9cm depth and thermocouples 2 and 4 were placed at 8 cm. Thermocouples placed through the same hole were horizontally spaced 1 cm apart.

4.2.1 Results

This experiment showed a 2.5°C increase in temperature over 10 minutes (Figure 2). The variation with height is approximately 2.5°C over 2 cm after 10 minutes of treatment. This increases to 10°C after 45 minutes of treatment. This is less significant than the increase observed in the smaller K42 bath as the ultrasound treatment was probably less concentrated.

Due to the height of the bath it was difficult to determine the accurate depth of the probes. However it is quite clear that like the smaller K42 bath, a vertical temperature gradient exists when treating bread dough with ultrasound using a bath. This again shows that there is an uneven distribution of sound waves, and subsequent physical and chemical effects, through the dough.

A second series of measurements, where toothpicks were used to keep the thermocouples straight, did not solve the problem of accurately determining the depth as the thermocouples still tended to enter the dough at an angle. However, results from this experiment confirmed the findings discussed above.

4.3 Effect of Ultrasound on the Work Requirement to Mix Dough

Dough was pre-mixed (0.5 - 0.7 Wh/kg) in the 125g mixer and then given one of two treatments (Table 1):

I. Remove from mixer and treat with ultrasound in the K42 bath for 10 minutes.

II. Remove from mixer and rest for 10 minutes. No ultrasound.

Each dough was then returned to the mixer and mixed to peak. The mixing curve was analysed to determine the optimum MDD work input. The results are outlined in Table 1:

Table 1. Effect of Ultrasound on the Optimum Work Input for Dough - K42 Bath

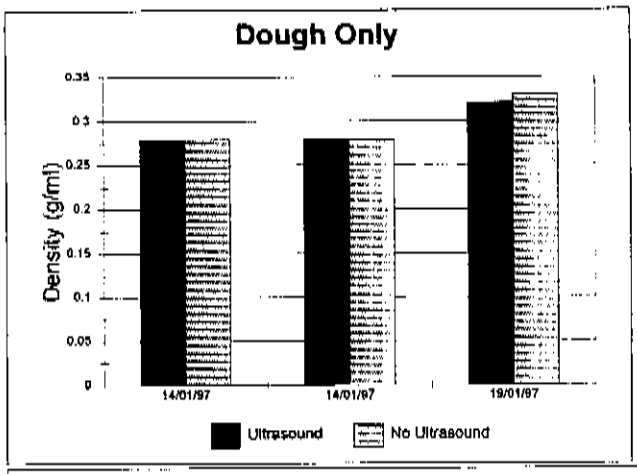
	Pre-mix (Wh/kg)	**Mixing curve peak** (Wh/kg)	**Peak temp** (°C)
Ultrasound 1	0.5	9.6	30.8
Ultrasound 2	0.5	9.4	30.2
Ultrasound 3	0.7	7.4	30.8
No Ultrasound 1	0.5	9.1	28.5
No Ultrasound 2	0.5	9.9	28.6
No Ultrasound 3	0.7	8.2	30.0

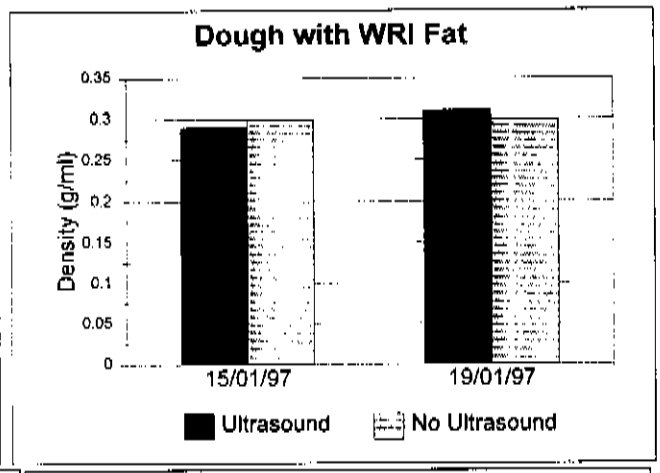
The average work required for the treated dough was 8.8 Wh/kg and the average work required for the untreated dough was 9.1 Wh/kg. However, the 0.3 Wh/kg difference was not significant. In later experiments, when a flour-water slurry was treated with ultrasound before mixing (see 5.1), the shape of the mixing curve changed, but again there was no change in work input.

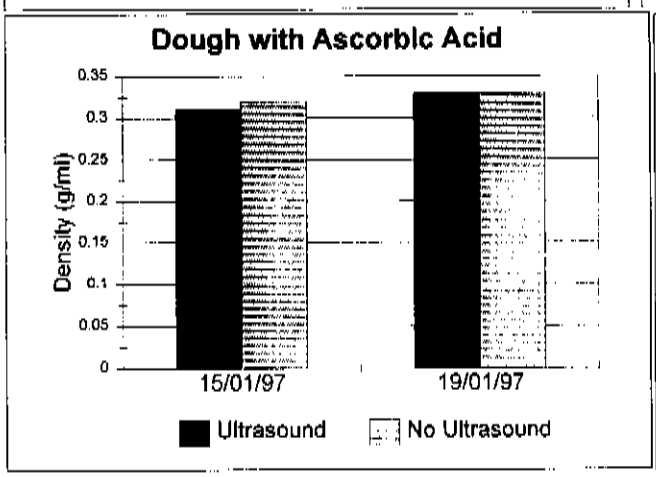
4.4 Effect of Ultrasound on Baking Quality of Doughs Treated in an Ultrasound Bath

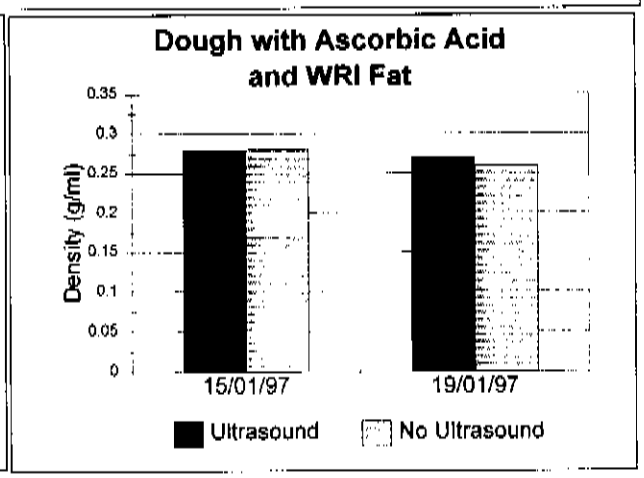
To assess the effects of ultrasound on baking quality using an ultrasound bath, a series of different recipes was tried. Doughs contained no additives, WRI fat or ascorbic acid or both additives. Two methods of ultrasound treatment were used. For the **pre-mix treatment**, doughs were mixed in the 125g mixer for 1 Wh/kg and then treated with ultrasound or left to sit for ten minutes, similar to the treatments in Table 1. The dough was then returned to the mixer and mixed to peak (work input approximately 10 Wh/kg). Processing (intermediate proof, moulding, final proof and baking) then continued as normal. For the **rest treatment**, doughs were treated with ultrasound for 10 minutes after mixing during the rest (intermediate proof) period. The 1kg BP mixer and 125g mixer were both used for mixing these doughs so that the FX10 and K42 ultrasound baths could be used respectively. All loaves were measured for weight, volume, texture and crumb strength. All results are shown graphically in the following three pages.

Density Variation with PreMix Treatment

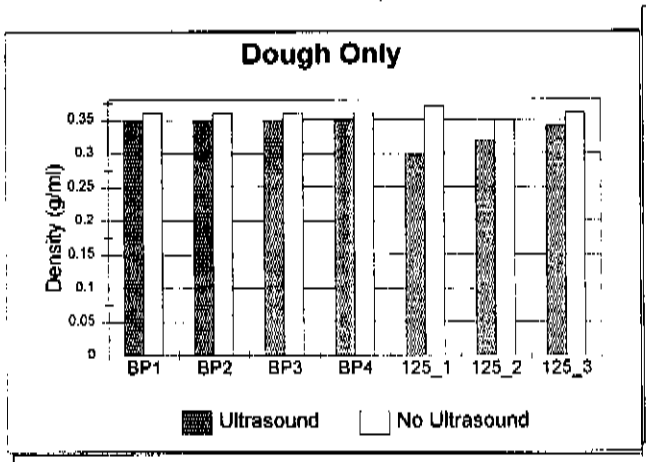


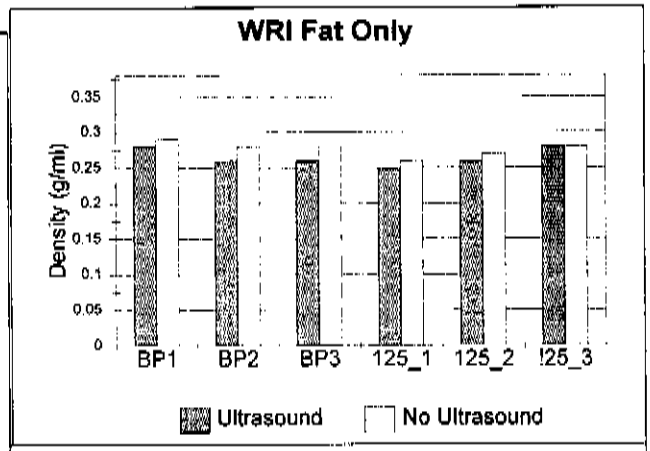


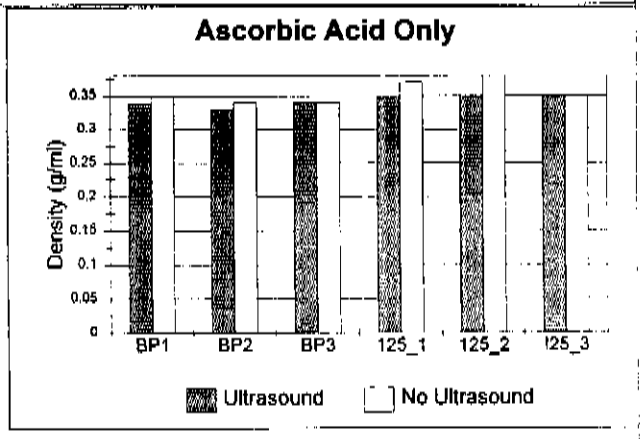


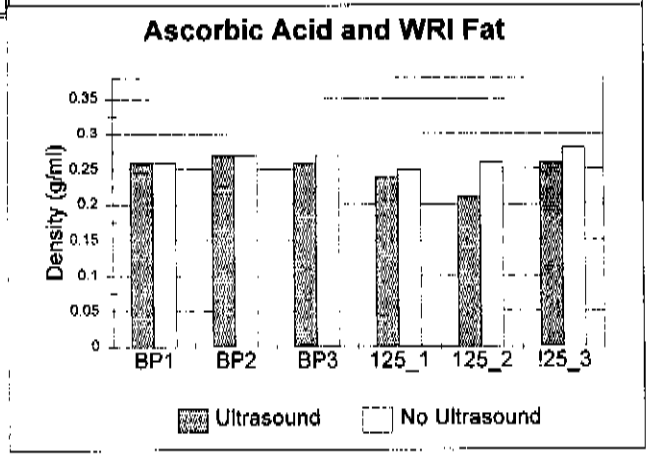


Density Variation with Rest Treatment

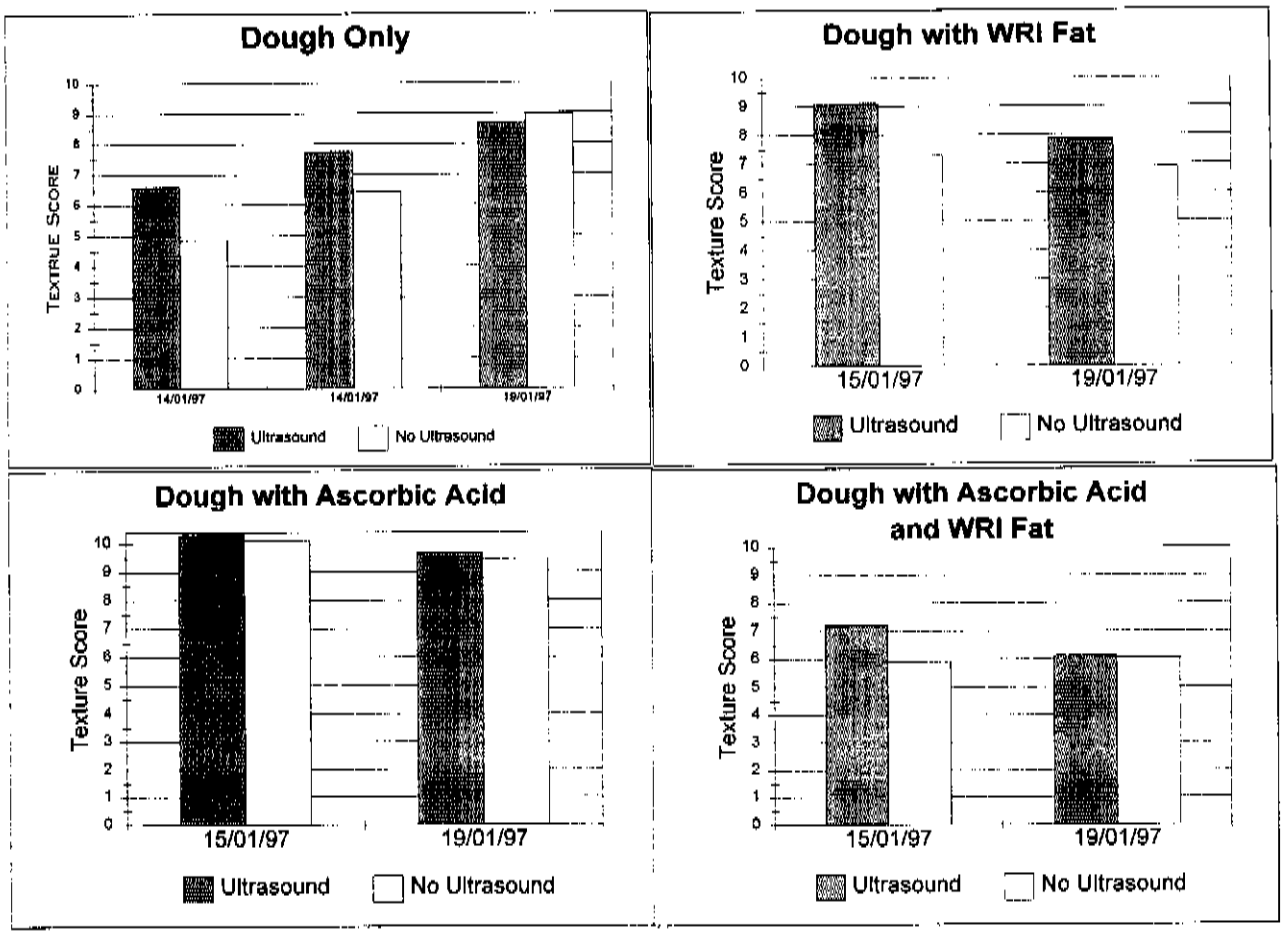




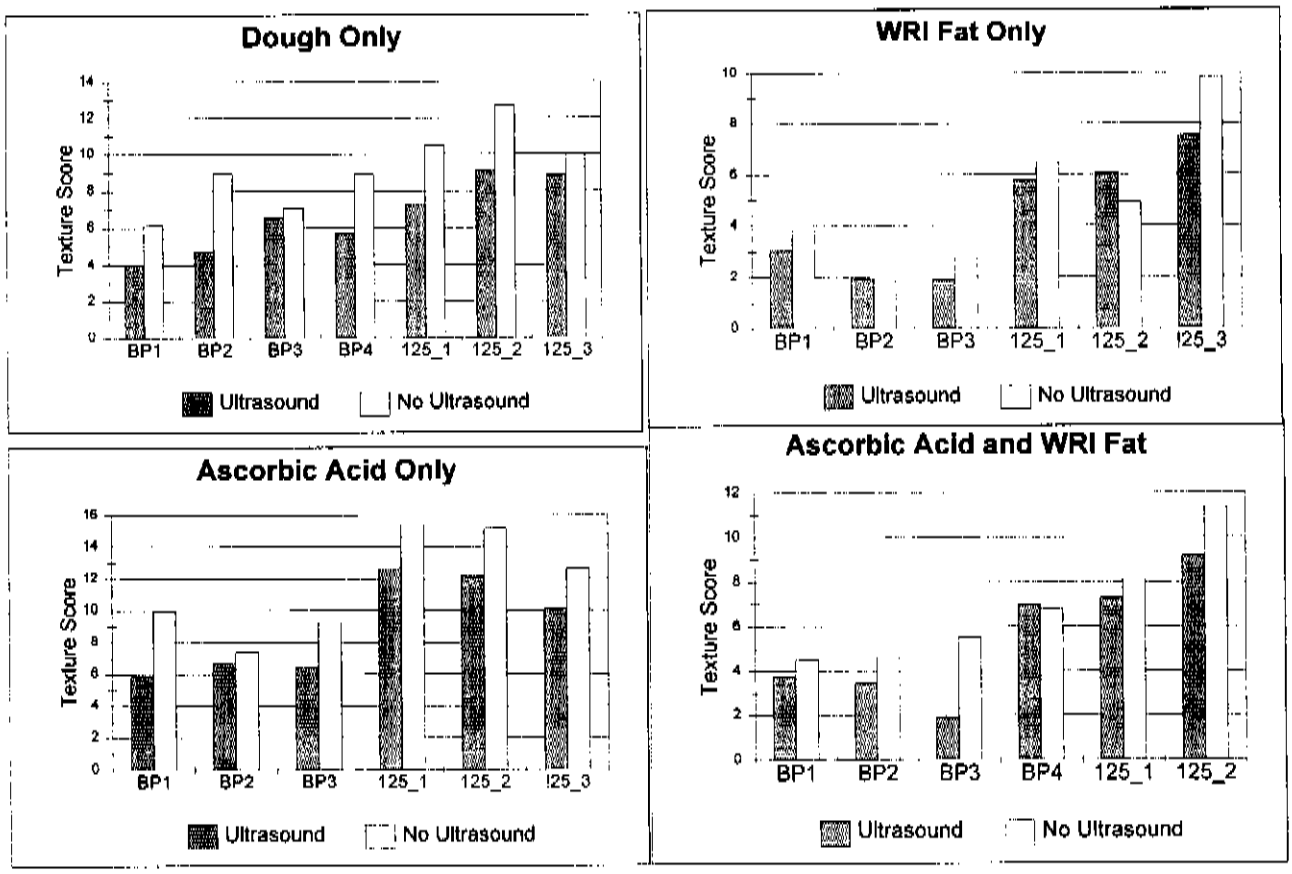




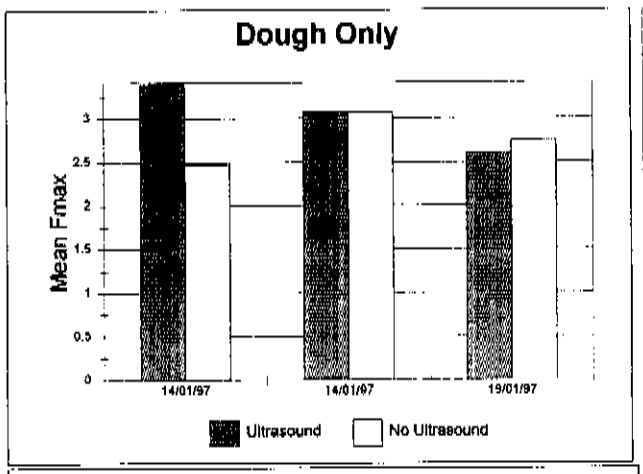
Texture Variation with PreMix Treatment

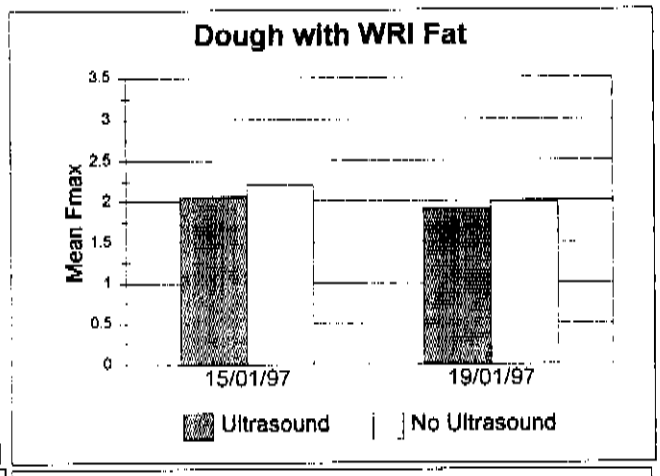


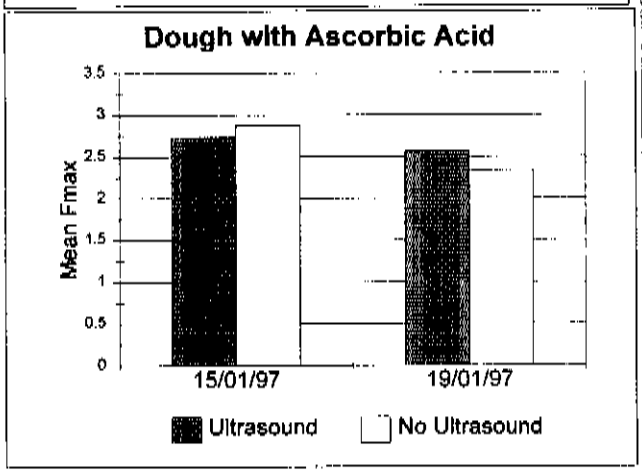
Texture Variation with Rest Treatment

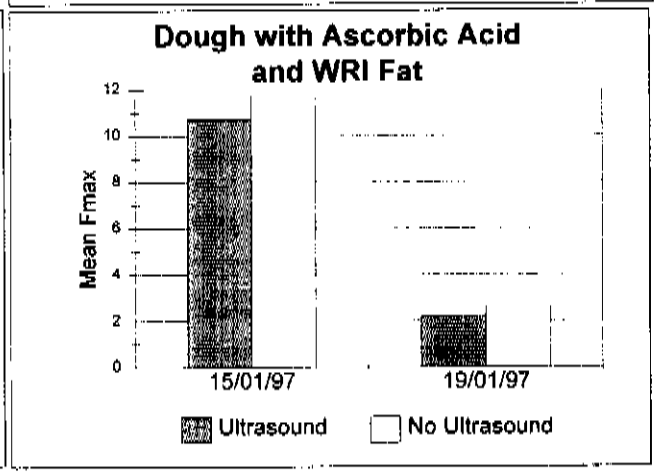


Crumb Strength Variation with PreMix Treatment

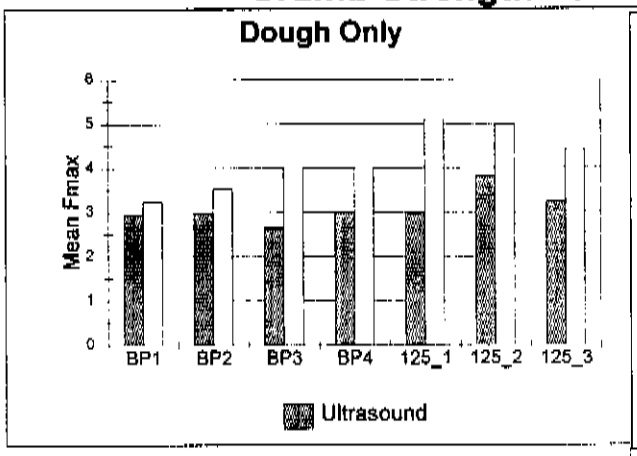


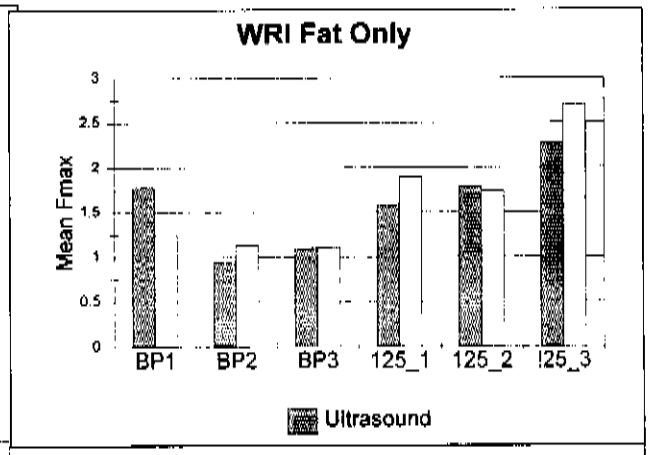


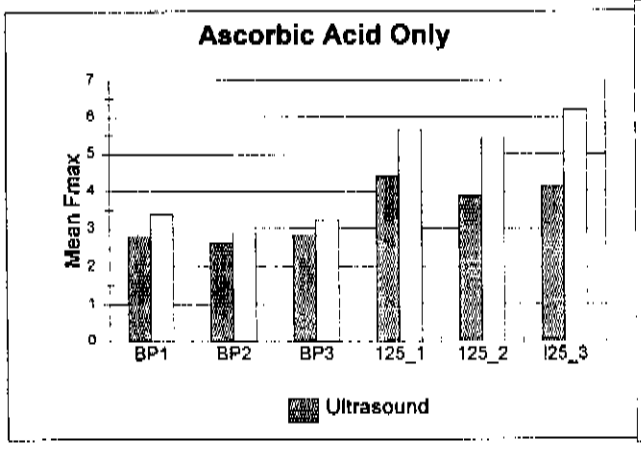


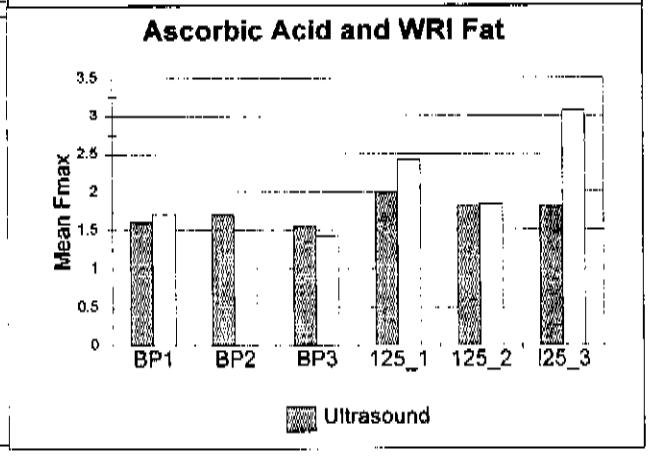


Crumb Strength Variation with Rest Treatment









4.4.1 Loaf Density Variation

Weight and volume measurements were used to determine the density of each loaf. This allowed the full-size and pup loaves to be directly compared. The following observations were made:

- Loaves from doughs that received the pre-mix treatment showed minimal variation in density
- Loaves from doughs that received ultrasound treatment after mixing had lower densities than those not receiving ultrasound. The difference was generally 0.02 g/ml but was as high as 0.07 g/ml in one case.

4.4.2 Crumb Texture Variation

- Crumb texture scores were generally only slightly higher for the loaves whose doughs had received ultrasound in the pre-mix method, compared with the non-treated controls.
- For doughs that received ultrasound treatment during rest, the crumb texture scores were lower than for loaves whose doughs were not treated with ultrasound during rest. This is in agreement with the loaf density results. The crumb texture differences were more noticeable for loaves from doughs without additives or ascorbic acid only.

4.4.3 Crumb Strength

- Ultrasound treatment of doughs during rest after mixing lowered the crumb strength (F_{max}) of loaves whose doughs contained no additives or ascorbic acid only. Loaves containing only WRI-fat, or ascorbic acid and WRI-fat, did not show a consistent trend.

5. APPLICATION OF ULTRASOUND DURING MIXING

Ultrasound is a high frequency vibration capable of breaking chemical bonds and increasing the rate of a chemical reaction. Cavitation on the tip of an ultrasonic probe is responsible for increased rates of reaction as it produces a high local pressure and temperature .

Because of the general lack of success and difficulties with the experiments that were discussed above, this second phase of the project concentrated on ultrasound application during the mixing process. Two methods of sonicating the dough during mixing were tried. The first used a 125g mixer with the tip of the ultrasound probe mounted in the bottom. However, the results were inconsistent and we concluded that attenuation, as demonstrated by the temperature measurements in the ultrasound baths (see 4.1 and 4.1), was probably the major problem. That is, the dough was too thick to conduct the vibrations of the ultrasound. Therefore, our second approach was to sonicate a slurry of 25 % of the flour and the water and then add the sonicated slurry to the remainder of the flour in the mixer. Treatment of the flour-water slurry would be similar to the bond disruption process used when solubilising gluten proteins for HPLC analysis.

5.1 Sonicating the Dough During Mixing

The Branson ultrasound probe that was used has a tip of approximately 12mm in diameter. Initial tests involved placing this tip into a stationary dough. However, like the ultrasound baths, it was found that the dough did not conduct the ultrasound effectively and only a small area around the tip was affected. Therefore, for better coverage of the dough, the probe was mounted inside the base of a 125 gram mixer, using an O-ring as a seal, where the dough could circulate over the tip. The mixer was run at both the standard speed of 150 rpm and at 75 rpm. The slower mixing speed gave the dough a longer exposure to the ultrasound.

5.1.1 Method

Two experiments were carried out with the ultrasound probe mounted in the mixer. The first experiment examined the torque vs work input curve and the second involved baking the samples. All mixing curves were recorded on a computer.

For Experiment # 1 (125g flour, 2.5g salt, 80ml water), when all the ingredients had been added to the mixer, the mixer was run until the torque had reached its peak value. Then in Experiment #2 (125g flour, 2.5g salt, 1g sugar, 1.6g WRI-fat, 0.0125g ascorbic acid, 3.8g yeast, 80ml water), where the doughs were to be baked, each dough was mixed to its peak work input. Eight runs were made for each experiment. At each mixing speed, two doughs were treated with ultrasound (the ultrasound was set on full power at 72 % duty cycle) and two doughs were mixed without ultrasound treatment. The doughs in Experiment #2 were baked after 10 minutes intermediate proof, moulding and 45 minutes in the final prover (40°C; 80-90% relative humidity). The loaves were left to stand for 24 hours before their volumes were measured and their textures scored.

5.1.2 Results

In these two experiments, the ultrasound probe was mounted in the bottom of the 125 gram mixer with the probe's tip flush with the mixer's base plate. The idea behind this mounting was that the dough would circulate over the ultrasound tip and more of the dough would be exposed to the ultrasound than if the probe was placed in a stationary dough. The results did show a difference between the ultrasound and non-ultrasound mixing curves at both 75 rpm and 150 rpm. The peak of the ultrasound-treated dough mixing curve was on average at a lower torque and occurred later than the corresponding non-ultrasound mixing curve. The difference, however, was minimal and after baking the loaves in Experiment # 2 there were no loaf quality differences that could be attributed to ultrasound treatment.

5.2 Sonicating a Flour-Water Slurry

To obtain better conduction of the ultrasound a slurry of 25 % of the total flour and all the water was treated before being added to the rest of the flour and other ingredients in the mixer. This method of starting the mixing process with a slurry is similar to a sponge and dough process. The effects of the ultrasound were compared with varying amounts of WRI-fat, ascorbic acid and salt. Experiment #3 investigated the torque vs work input mixing curves and the results (Figures 3-5) were used to find the work input required to reach the peak torque. Experiment #4 involved mixing the doughs to the work input that corresponds to the torque peak and then baking (Figures 6, 7). Experiments 5 & 6 concentrated on the addition of WRI-fat and ascorbic acid respectively (Figures 8-11).

5.2.1 Method

To treat the slurries with ultrasound, the probe was mounted to fit inside a 250ml beaker on a magnetic stirrer. A temperature probe was also mounted in the beaker.

The preparation of the treated slurry was slightly different to the control slurry. Because it was necessary to have the slurries at approximately the same temperature before they were added to the mixer, and because the ultrasound treatment warmed the slurry, the control slurry had to be made initially warmer. The ultrasound-treated slurry used tap water at approximately 15 °C; it was mixed with a teaspoon and then ultrasounded at 100 % power on the 60 % duty cycle. The magnetic stirrer was used to circulate the slurry during ultrasound treatment. Treatment stopped once the slurry reached 35 °C, which took approximately two and a half minutes. The control slurry used warm water (45 °C) which was also mixed with a teaspoon and then magnetically stirred for two and a half minutes. After this time the control slurry was also at 35 °C.

The slurries were then added to the remainder of the flour in the 125g mixer through the funnel that is usually used to add the water. The mixer was run at 150 rpm for all of these experiments. For the experiments where the doughs were baked, they were mixed to the peak work input that corresponded to the torque peak found in Experiment #3. Four runs were used for each variation of the recipe; two runs with ultrasound and two without.

Baking recipes, dough make-up and loaf scoring were as above for Experiment #2 (see 5.1.1).

5.2.2 Results

Experiment # 3 The mixing curves of the ultrasound-treated doughs again showed a lower peak torque and a longer time to reach the peak than the non-ultrasound doughs (Figures 3-5). This was most evident in the straight flour and water doughs but was less so when salt and ascorbic acid were added together. The work inputs required to reach the torque peak were very similar with the only significant difference being found in the flour and water doughs where the ultrasound resulted in more work being required for the dough to reach peak development.

Experiment # 4 The volumes of the loaves from ultrasound-treated doughs were consistently higher for most combinations of salt, WRI-fat and ascorbic acid (Figure 6). However, when the full recipe was used, the non-treated, control doughs gave loaves with greater volumes. The effects on crumb texture with ultrasound treatment, were more apparent in loaves that contained salt and WRI-fat but no ascorbic acid (Figure 7). The ultrasound treatment gave crumb with a finer structure and raised the question of whether ultrasound may do the same job as ascorbic acid.

Experiment # 5 To more extensively investigate the effects of the ultrasound on doughs with WRI-fat, Experiment # 5 used 0.5, 1 and 2 times the amount of WRI-fat as Experiment #4 (Figures 8, 9). A run was also completed where the WRI-fat was added after the slurry had been treated with ultrasound. The volumes of loaves from the ultrasound-treated doughs were again slightly larger, except when twice the WRI-fat had been added. However, the crumb textures of the loaves from the ultrasound treatments didn't show the improvements experienced in Experiment # 4 and were difficult to tell apart (Figure 9).

Experiment # 6 To see whether ultrasound could be used as a substitute for ascorbic acid runs were done where 33 and 66 ppm ascorbic acid were used in the slurries treated with ultrasound, and a run where 66 ppm ascorbic acid was added after the slurry had been ultrasound-treated. The improved loaf volumes and textures suggested that ultrasound could be used in conjunction with lower levels of ascorbic acid (Figures 10, 11).

Figure 3. Effect of Slurry Ultrasound Treatment on Mixing Time to Peak Torque

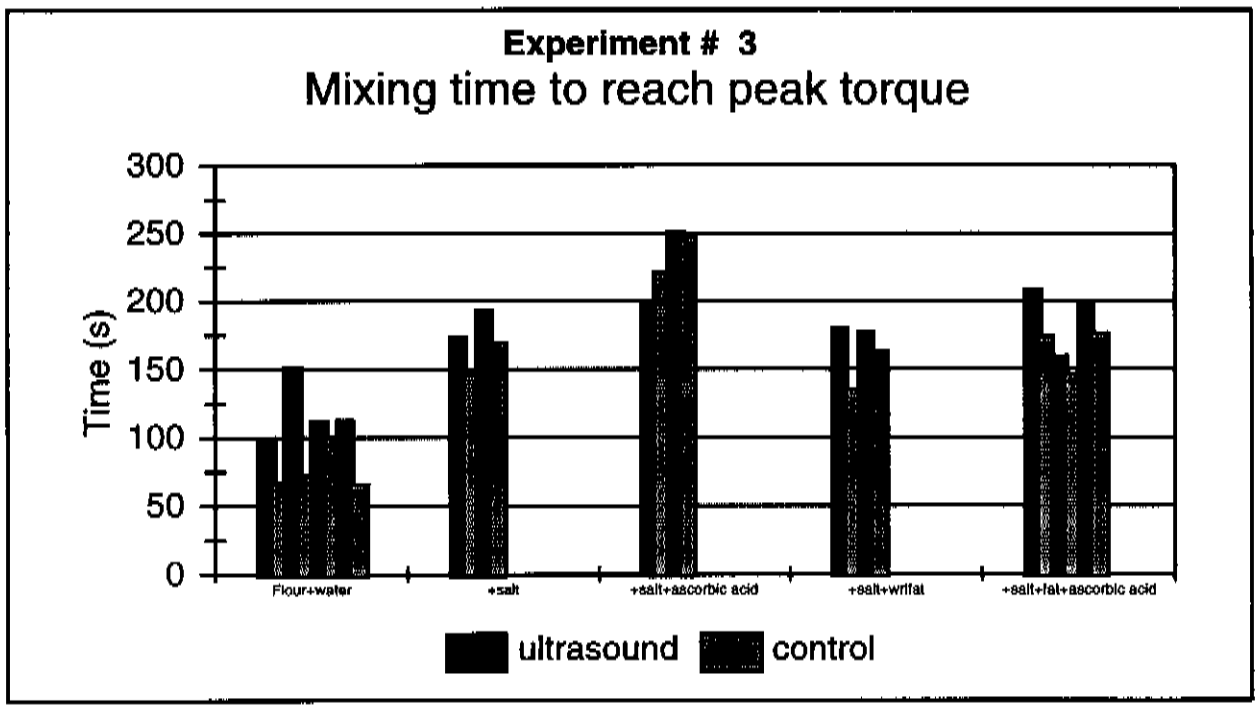


Figure 4. Effect of Slurry Ultrasound Treatment Peak Torque

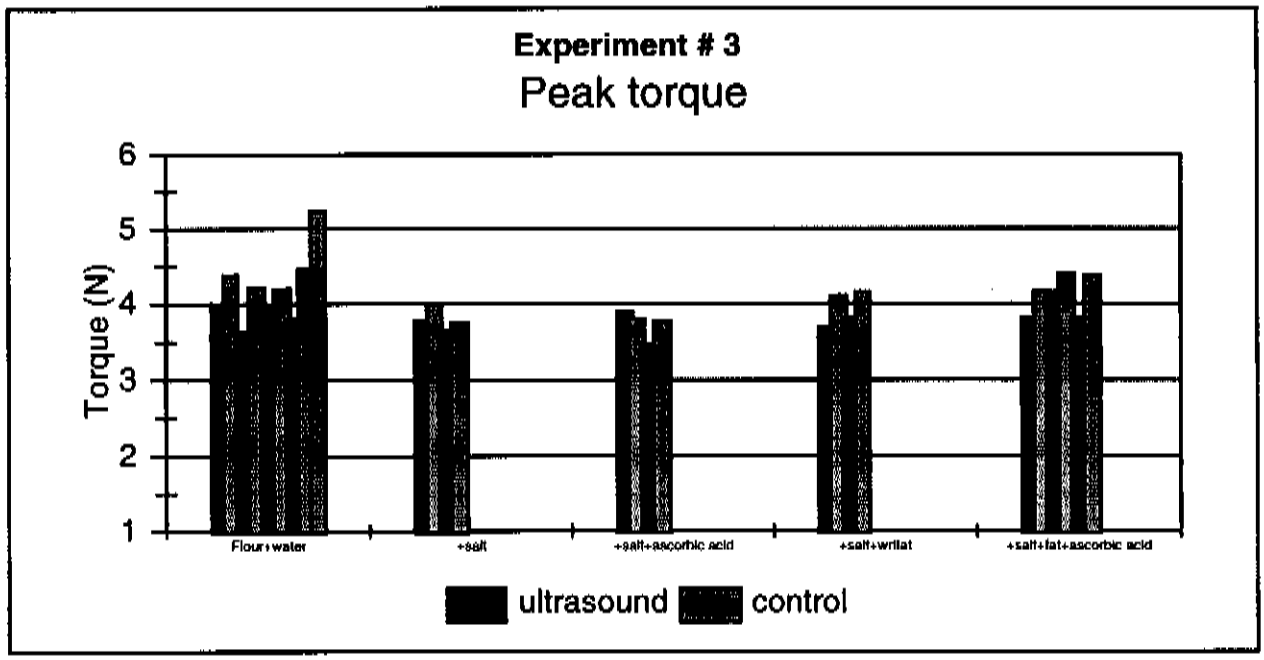


Figure 5. Effect of Slurry Ultrasound Treatment on Work Input to Peak Torque

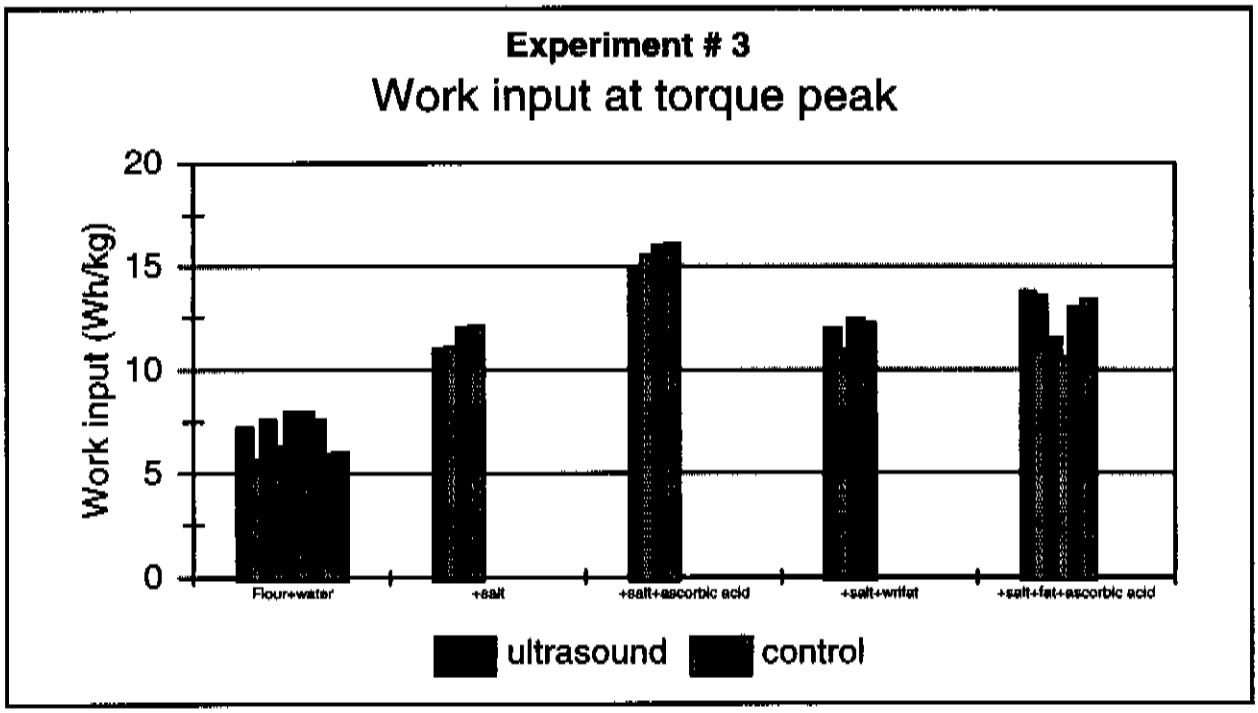


Figure 6. Effect of Slurry Ultrasound Treatment on Loaf Volume

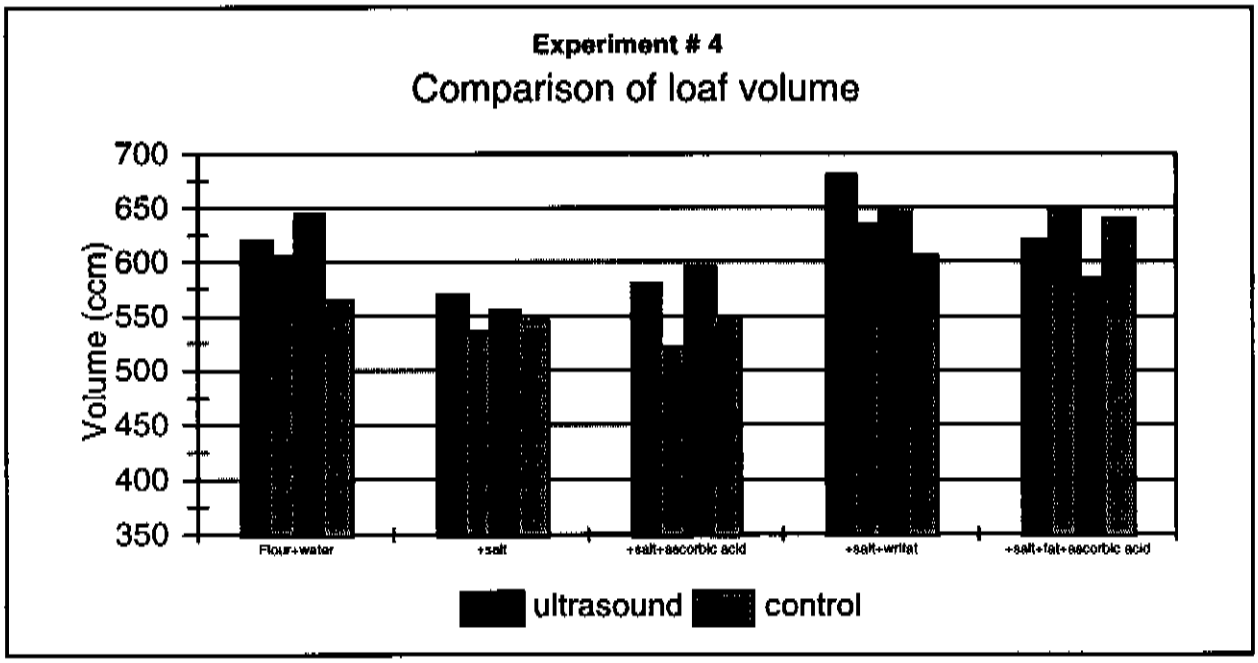


Figure 7. Effect of Slurry Ultrasound Treatment on Crumb Texture

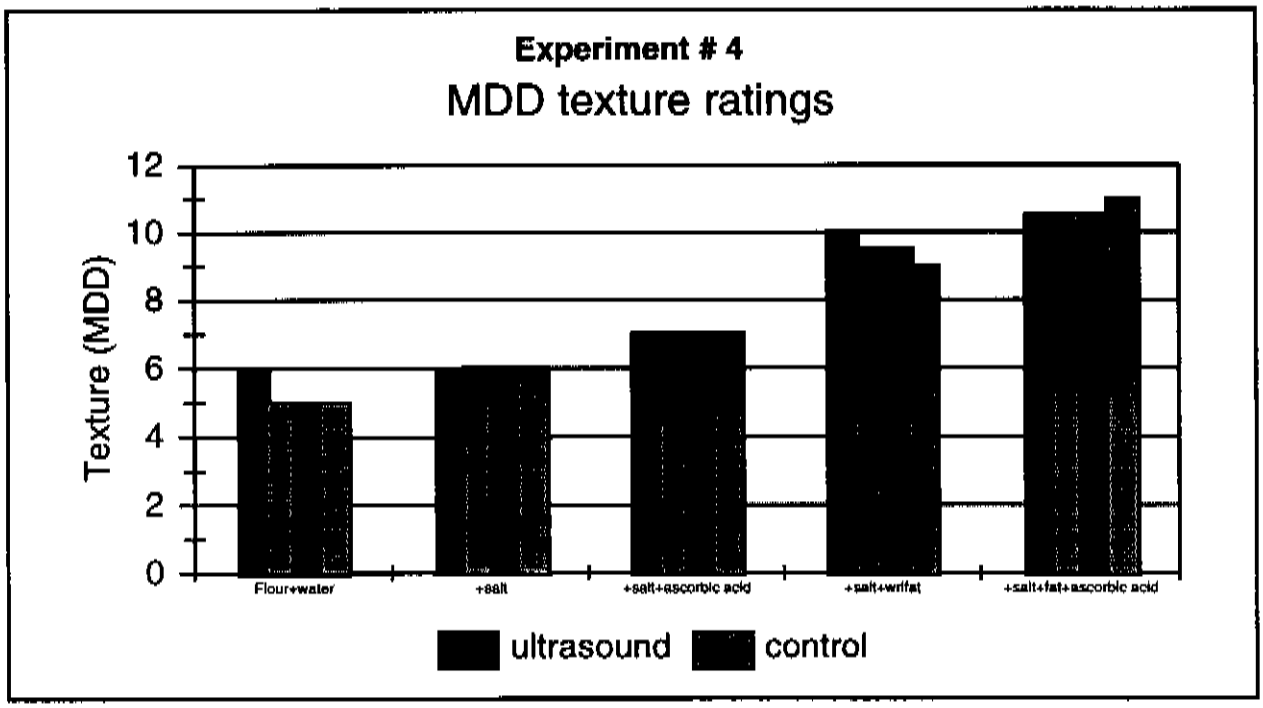


Figure 8. **Interactions of WRI-Fat in Ultrasound Treatment of Slurries - Effect on Loaf Volume**

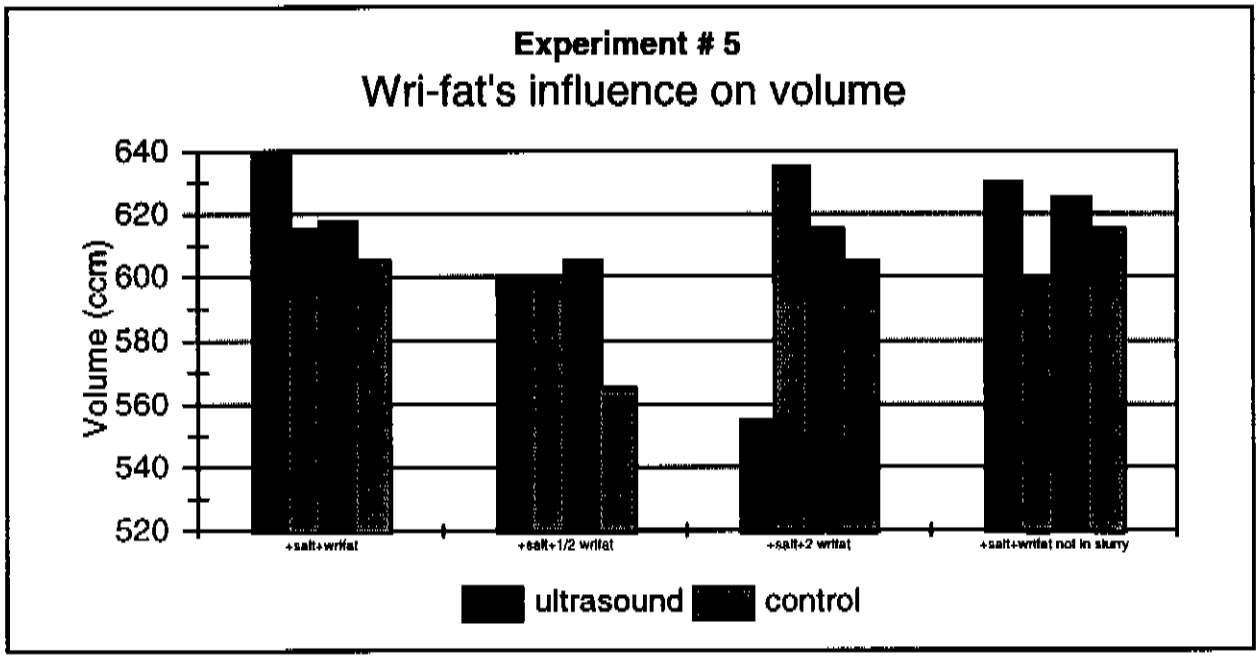


Figure 9. **Interactions of WRI-Fat in Ultrasound Treatment of Slurries - Effect on Crumb Texture**

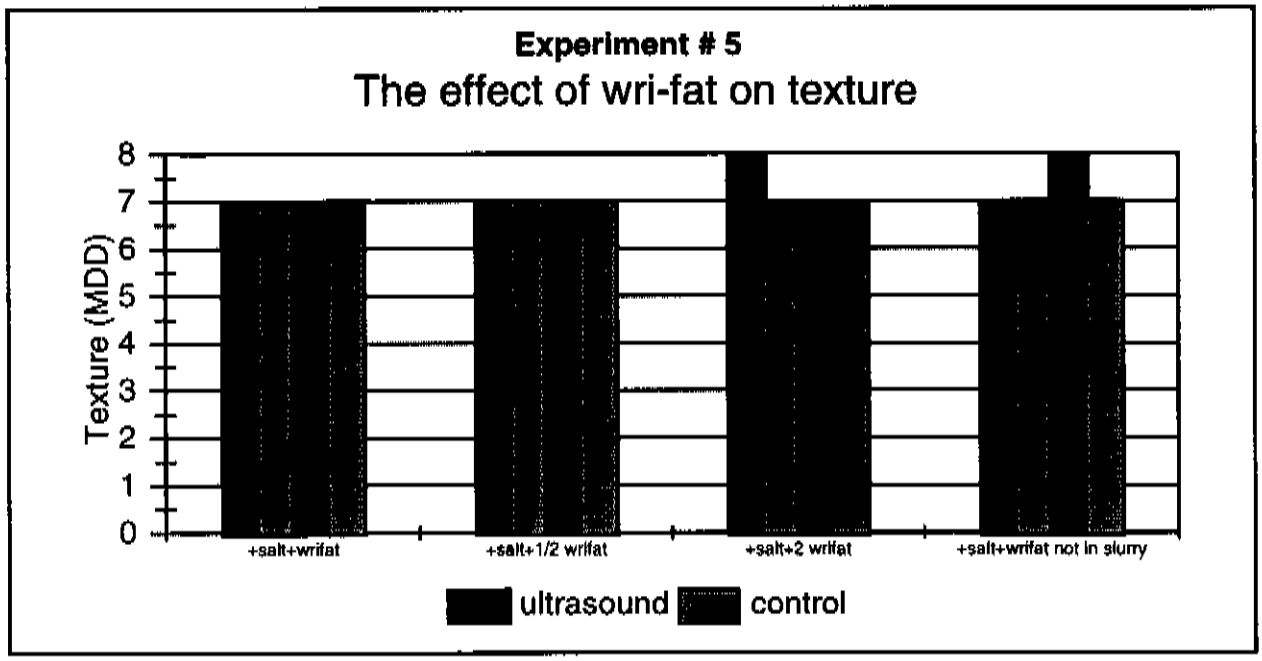


Figure 10. **Interactions of Ascorbic Acid in Ultrasound Treatment of Slurries - Effect on Loaf Volume**

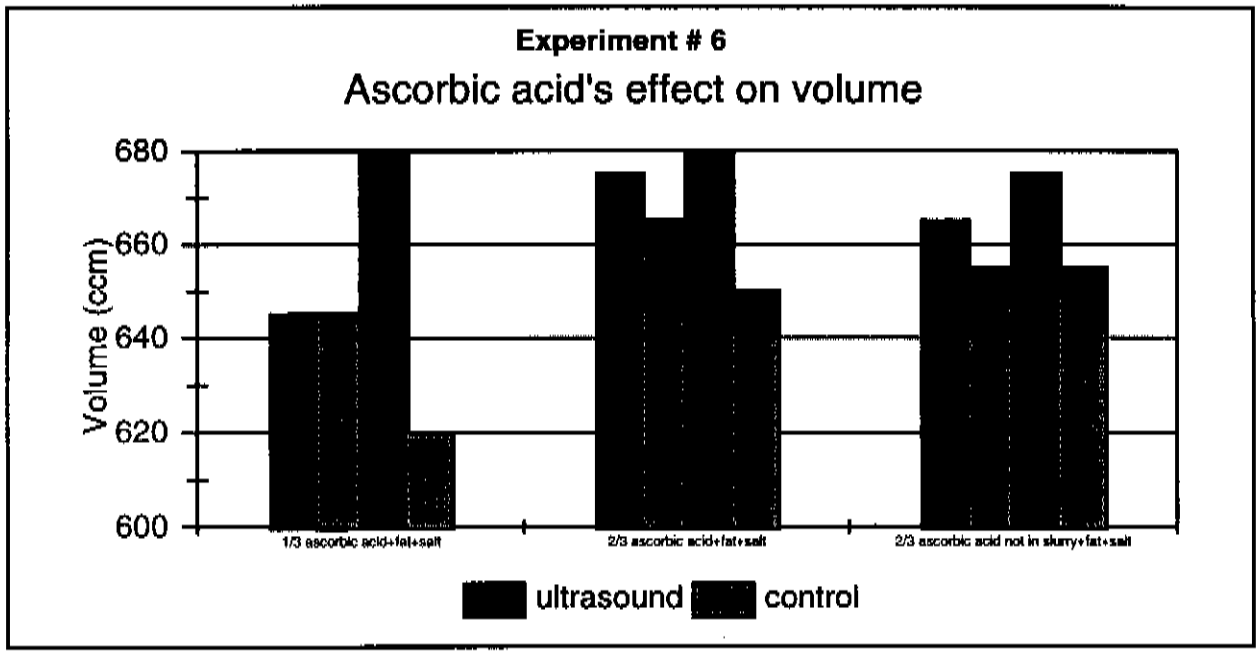
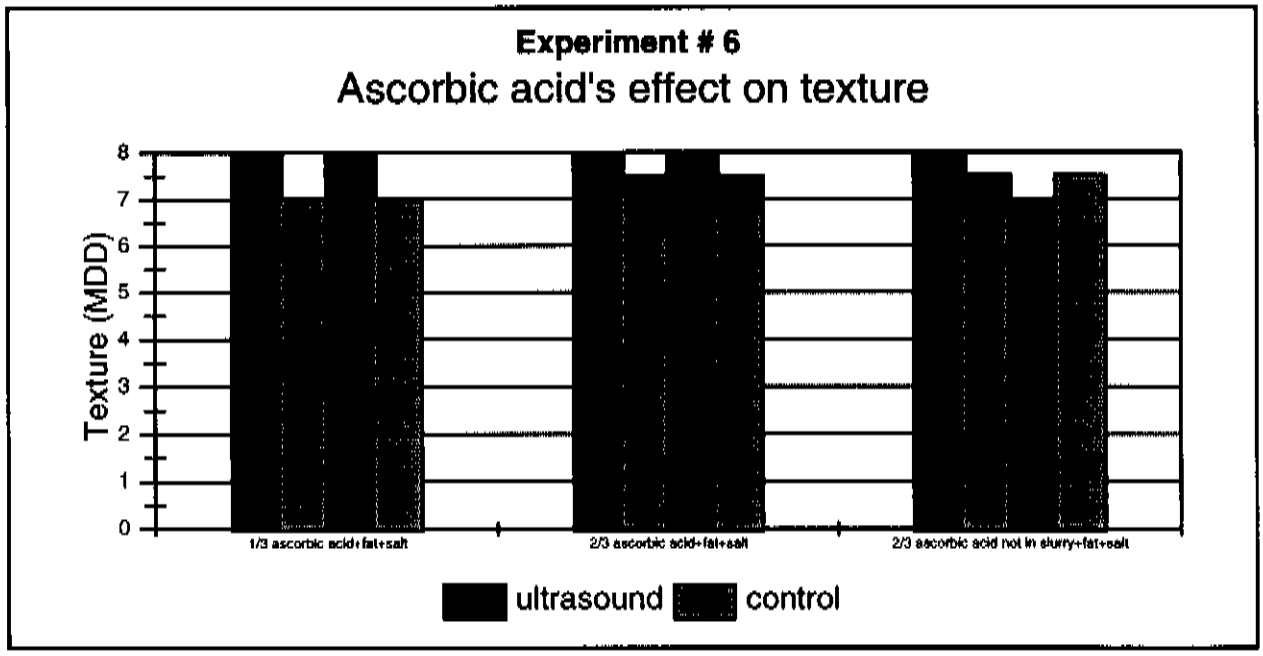


Figure 11. **Interactions of WRI-Fat in Ultrasound Treatment of Slurries - Effect onCrumb Texture**



6. SUMMARY

Our experimental work was approached in two phases. Firstly, we used ultrasonic cleaning baths to treat bread dough by sonicating the dough either after a short pre-mix or after completion of mixing. The second phase of experiments looked at ways of applying the ultrasound during the mixing process, using an ultrasonic probe.

- Bread dough strongly attenuates ultrasound, and unevenly applies sound waves through a proving bread dough. This results in significant temperature gradients throughout the dough.

- There were no significant changes in MDD mixing requirement as a result of ultrasound treatment of dough after a short pre-mix, and there were no significant effects on loaf quality.

- Ultrasound treatment of doughs during rest after mixing lowered the crumb strength (F_{max}) of loaves whose doughs contained no additives or ascorbic acid only. Loaves containing only WRI-fat, or ascorbic acid and WRI-fat, did not show a consistent trend.

- Application of ultrasound through the base of a small batch mixer (125g flour capacity) was not successful. Like the ultrasound bath treatments, attenuation of the ultrasound, by the viscous dough, was the problem.

- After applying ultrasound to 25% flour-water slurries (sponge method), and then mixing the remaining flour and ingredients, the MDD mixing curves were flatter and longer. While this is consistent with the theory that ultrasound breaks down chemical bonds, there was no measurable change in MDD work input to peak when all ingredients were used. However, for flour and water doughs, with no ascorbic acid, salt or fat, ultrasound treatment of the slurry resulted in more work being required for the dough to reach peak development.

- For lean dough recipes, loaves that were baked showed a small increase in volume after the ultrasound treatment of the flour-water slurries. The occasional loaf also showed a finer crumb texture. However, when the full recipe was used, the volumes were lower than the non-treated controls.

- The improvements from treating flour-water slurries were small, may depend on the dough formula and currently do not seem to be worth the effort of using the ultrasound.

- If used in conjunction with lower levels of ascorbic acid, the savings in ascorbic acid use and the product quality benefits from ultrasound treatment of slurries would have to offset the capital expense of setting up sonication systems in bakeries.

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