QUALITY WHEAT
CRC PROJECT REPORT

Program 3b Processing of Wheat and Wheat Products

Project 3.4.1 Process measurement and control for dough mixing and make-up plants

Comparison of industrial and laboratory dough mixers and development

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1 EXECUTIVE SUMMARY

This report concentrates on advances made in the comparison of doughs and dough development in industrial and laboratory scale mixers. The goal of this Quality Wheat CRC Ltd project is to be able to use a laboratory system for predicting how a flour will perform in a commercial bakery and to commercially use a measure of dough development for process control.

■ This work has, for the first time, used a range of dough property measurements to define and compare doughs from small scale and industrial scale mixers. More importantly, the measurements have been done on full-formula doughs which makes the measurements directly applicable to an industrial bakery. We have been able to show structural similarities in doughs mixed from 10 g flour through to doughs mixed from 350 kg flour.

■ A dough probe, which measures changes in the consistency of dough as it is mixed, has now been used to record mixing curves for slow speed mixers commonly used by plant bakeries in Australia and New Zealand.

■ Dough micro-structure was not uniform in doughs from an industrial horizontal mixer. However, this non-uniformity also appears in doughs mixed in some small-scale mixers.

■ The micro-structure of dough samples mixed to peak dough consistency depends on mixing speed. The general effect of higher mixing speeds is a finer, more homogenous protein network. A secondary effect, but with the most noticeable influence on product quality, is that faster mixing incorporates more air cells into dough and gives finer crumb textures.

■ We studied the effects of dough mixing on the crumb properties of loaves from a slow speed industrial mixer. Crumb extensibility and softness both showed improvement as the extent of dough development increased in severely under-mixed doughs. However, about the mixing optimum there was little change in these crumb properties. Crumb strength was not affected, contrary to laboratory mixer studies, and we attribute this difference to the four-piecing of the plant bakery doughs.

In loaves from two different types of variable speed laboratory mixer, crumb texture improved as mixing speed increased.

■ The dough make up plant in the industrial bakery was shown to affect the dough structure developed during mixing. The J-Divider destroyed some of the protein structure developed during mixing and it wasn't until after moulding that some of the divider damage was reversed.

Agreement between dough mixers of different design and capacity can be improved and fine-tuned if the mixers have variable speed mixing capability. R & D laboratories should take this into consideration when designing or ordering new mixers. This raises the possibility that there could be better agreement between similar types of mixers in plant bakeries (assuming that the rest of the plant is similar) if there was capability for variable speed mixing on industrial mixers. The latter might also allow bakeries to improve crumb texture in products made from single-pieced doughs.

2 INTRODUCTION

Many small-scale devices have been developed to measure changes in dough characteristics during and after mixing. These include the farinograph, extensograph, mixograph, alveograph and various mechanical dough development and bulk fermentation mixers. Clearly, an important question is how well do these small-scale tests predict actual processing performance? Dissatisfaction in the baking industry suggested that some of the traditional tests did not predict industrial processing performance. Work published by Oliver and Allen (1992) attributed part of this to the failure of these tests to use full dough formulations.

Dough development can be monitored in industrial mixers by measuring power consumption (this method does not work for all mixers), or by using a device to measure the mechanical consistency of the dough.

Much of the project in its current form arose from dough mixing research that began at Crop & Food Research about five years ago and is funded by the New Zealand Foundation for Research Science and Technology (FfRST). One of the outcomes from this research was a probe (Wilson & Newberry 1995), now called the Dough Probe, that was modified from a design published by Canadian researchers in the early 1980's (Kilborn & Preston 1981). However, a major improvement was made in the way raw data were processed, using Fast Fourier Transforms (FFT), to give interpretable mixing curves. Consequently, the dough probe was used by Crop & Food Research for further research into dough development in industrial scale Tweedy-type mechanical dough development (MDD) mixers (Wilson & Newberry 1995; Wilson et al. 1997).

In summary, the pre-CRC work made two major contributions to studies of dough mixing. Firstly, the study enabled the first direct comparison of the mixing requirements of flours in both industrial and laboratory dough mixers. This work was done for the mechanical dough development (MDD) process. The study showed that the work input to peak dough consistency on a Tweedy type MDD mixer (90 kg flour capacity) was strongly correlated ($R^2 = 0.88$, $n = 14$) with the work input for the same flours on an MDD laboratory mixer (125 g flour capacity) at Crop & Food Research (Wilson et al. 1997). The second contribution was that if the raw mixing data (force readings from a load cell) did not give a readily interpretable mixing curve, the data could be further analysed using FFT to give a power *vs* time curve with a better defined mixing peak (Wilson & Newberry 1995).

The dough probe allowed mixing curves to be collected from mixers from which traditional power consumption mixing curves could not be obtained - due to relatively constant power consumption. While the study was limited in scope, it demonstrated that laboratory mixing can have direct industrial relevance.

In parallel with dough probe work at Crop & Food Research, the Bread Research Institute (now BRI Australia Ltd) was developing its new Easy-mix system for monitoring power consumption during mixing (Kalitsis & Quail 1996; Quail 1997). Easy-mix was innovative in that not only could mixing curves be followed by a mixer operator in real time but could also be used to control mixing - through the operator defining when the mixer was to be stopped (eg, 20% past peak dough consistency).

Research using the dough probe and Easymix software has given a direct means of studying mixing processes in industrial-scale mixers and optimising processing conditions.

With the formation of the Quality Wheat CRC[1] in Sydney, a major portion of Crop & Food Research's in-kind contribution to the CRC has been through a continuation of this mixing research, funded by FfRST, as the CRC project "Process measurement and control for dough mixing and make-up plants".

A second aspect of this project was to measure changes in dough after mixing and relate these to processing quality. Using an Instron type of instrument, dough properties such as compression energy, stickiness (adhesion/cohesion) and relaxation time can be measured in one test (Larsen 1992). Relaxation times of doughs are useful for monitoring their degree of development (e.g., after mixing and moulding) and oxidation, and also relate to how sticky a dough is expected to be.

However, Instron-type instruments are usually very heavy and immobile, not suitable for on-the-spot measurements in bakeries. Hence Crop & Food Research developed an Instron-type instrument that is portable (weighs only 5 kg) and is interfaced with a laptop computer for

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[1] The Co-operative Research Centre for Quality Wheat Products and Processes

measuring dough and crumb properties in bakeries (Morgenstern, Lau et al. 1995). The instrument is called a Textron.

It was envisaged that the Textron could be used in this project to research changes in doughs during and after mixing. Moulding (more specifically, sheeting during moulding) compresses a dough similarly to compression instruments such as the Instron, and compression energy can be used as a measure of dough consistency. Hence, research such as this could lead to measurements of dough properties during moulding being used to provide feedback to the mixing process - e.g. for adjustment of dough water content so that the dough is an optimum state for sheeting and fewer moulding faults occur.

During the first two years of the Quality Wheat CRC, work has been done that will lead to meeting the project's goal. Briefly stated, the project's goal is to be able to use a laboratory system for predicting how a flour will perform in a commercial bakery and to commercially use a measure of dough development for process control.

The expected outcomes from this project are a better understanding of what happens to dough in commercial bakeries, means for predicting how a flour will perform in a commercial bakery, and commercial use of a measure of dough development for bakery process control.

This report will concentrate on advances in the comparison of industrial and laboratory mixers. A subsequent report will discuss comparisons of laboratory mixers.

3 METHODS

3.1 Measuring mixing requirements in laboratory and commercial dough mixers

3.1.1 Laboratory mixers. For the mixing studies outlined in this report, two types of laboratory mixer were used. The first type was based on the small scale mechanical dough development (MDD) mixers described by Mitchell (1984, 1989). The mixing capacities were 10 g, 50 g and 125 g of flour, with the 10 g and 125 g mixers having variable mixing speed capability. The 50 g mixer operates at a fixed MDD speed (155 rpm). Typical dough development times at 150 rpm are about 2 minutes.

The mixing action of these three mixers is exactly the same, being scaled versions of the same basic twin-blade design - see Mitchell (1971).

The 10 g and 125 g mixers record 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 older 50 g mixer records a power curve, and work input is calibrated against the 125 g mixer.

The second type of mixer used in this study was an Autobake mixer - a variable speed (< 100 rpm) version of the basic twin Z-arm mixing design used in Morton mixers. Except for much lower mixing speeds, the Autobake is similar to the variable speed (< 330 rpm) Baker Perkins (BP) mixer used at Crop & Food Research (Larsen & Greenwood 1991). Like the Morton and BP mixer, the Autobake mixer mixes dough from 1 kg flour. Dough development times at 75 rpm are about 4 minutes.

Mixing curves for the Autobake mixer were recorded using "Powermix", a hardware-software interface that, similarly to Easy-Mix, records power consumption during mixing.

3.1.2 Industrial mixer. The plant bakery mixer was a Baker Perkins horizontal mixer, comprising three horizontal beater bars, with a mixing capacity of over 300 kg flour. The mixer operates at about 80 rpm, with typical dough development times around 7-8 minutes.

To record dough mixing curves, the mixer was fitted with the dough probe and Powermix was connected to the mixer operating console. Hence both methods for recording dough development were operated simultaneously.

Two attempts were needed to position the dough probe so that good mixing curves could be obtained. With the first attempt, the probe was positioned lower centre at the front of the mixer - where it was thought that the dough would strike the probe consistently and there was plenty of clearance between the probe and the beater bars. This configuration did not give a traditional mixing curve. Instead the dough's peak consistency (maximum force measured by the probe) was about 50 - 100 seconds after starting mixing, with a linear decline as the dough approached peak development (as assessed by the bakers and confirmed by microscopy). This happened even when the probe protruding inside the mixer was longer (150 mm *vs* 75 mm). On watching what was happening to the dough, we reasoned that as it developed more dough was wrapping itself around the beater bars and less dough was coming into contact with the probe. Therefore the probe needed to be repositioned so that it was much closer to the passing beater bars and in more constant contact with the developing dough.

The probe was repositioned higher up the front centre of the mixer, using the same hole as a temperature probe that had once been used on the mixer. For the measurement of dough development the 75 mm probe was used, which gave about 30 mm clearance from the closest pass of the beater bars. This position gave traditional mixing curves, with a well defined dough consistency peak at 7 minutes for the flour that was being used.

3.2 Defining and comparing dough and crumb properties

For the comparison of the effects of mixing on dough properties, a combination of light microscopy and physical dough property measurements, using the Textron, was used. For crumb properties, the Textron was used.

3.2.1 Microscopy. All dough samples collected for microscopy were prepared using methods described by Ray Moss (1974). Dough pieces of approximately 20x20x20 mm were carefully cut from larger doughs and put into chilled acidic glutaraldehyde (4°C) fixative. The samples in fixative were kept chilled for at least 18 hours after collection.

For microscopy, the fixed doughs were sectioned (approximately 8000x8000x10μm) on a cryostat microtome. The sections were then stained with Xylidine red and examined under a compound light microscope. For permanent record, photographs were taken of all sections and the microscope slides kept.

3.2.2 Physical dough property measurements. Unless stated otherwise, all doughs were "full formula". That is, they contained salt, improvers, fat and yeast, usually in the same proportions as the plant bakery we were working in. Dough physical properties were measured on the Textron using methods modified from those described by Larsen (1992). Data analysis software was written using ASYST (Morgenstern, Lau et al. 1995). The Textron method has similarities to the texture profile analytical methods widely used in the food industry (for example, as recently published by Wang et al. 1996), and was based on the way a baker assesses a dough - the dough is compressed and then the finger(s) are pulled away from the dough. Both actions give the baker a "feel" for the dough and allow a subjective assessment of the dough's properties. The Textron test that we use allows us to quantify the "feel" of the dough and provides long term consistency in the measurement of dough properties.

From one measurement, the properties of compression energy (CE), maximum tensile force (T), tension energy (TE, used as a measure of dough stickiness) and relaxation time (Rt) are obtained. CE is the area under the compression curve, Rt is the time between the compression peak and the beginning of the tension peak, T is the height of the tension peak and TE is the area under the tension peak.

CE, compression energy, is a measure of the extent to which the dough resists compression. A soft dough will have a higher CE than a firmer dough because the probe will meet less resistance during compression and it takes longer to reach the target compression force (1.5 N).

T, maximum tensile force, is similar to resistance to extension in an extensigraph, except that part of this force is dependent on the dough sticking to the probe while the probe is being pulled away.

TE, tension energy, is principally a measure of both how long and with what force the dough stays stuck to the probe - that is, how sticky the dough is.

Rt, relaxation time, gives us information about the state of oxidation and development of the dough. Properly oxidised or developed doughs have longer relaxation times than immature or under-developed doughs.

Definitions of Rt, CE and TE are slightly different to those originally published by Larsen (1992). As all the doughs in the current study were yeasted, the method for measuring relaxation times differed from that published by Larsen (1992) for non-yeasted doughs. This change was made to offset the effects of fermentation on relaxation time during the measurements. Relaxation times for all yeasted doughs were subsequently defined as the time taken to relax the dough by 75 g (0.75 N) after a 150 g (1.5 N) compression (Larsen & Wilson 1996).

For CE and TE, the definition of the area under the compression and tension peaks respectively is now in standard energy units (mJ).

For each dough, five replicate measurements were done, checked for outliers, and the results averaged. Outliers were rejected only if there was an obvious reason why the result should not be accepted.

3.2.3 Dough densities. 250 ml plastic measuring cylinders were filled with 30°C water to the 200 ml mark. To carry out a measurement, a dough piece (10-30 g) was cut off, weighed accurately (Wt_D), then dropped into a cylinder of water. The water that rose above the 200 ml mark was syringed off and weighed (Wt_W) in a previously tarred beaker. The density calculations for doughs mixed to 30°C were:

$$\text{Density} = 0.9957 \times Wt_D \text{ (grams)}/Wt_W \text{ (grams)}$$

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

The Textron 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 slice weight (g), crumb strength (Fmax (N) - the maximum force resisting the probe at the point of rupture), crumb extensibility (Dmax (mm) - how far the crumb has stretched to the point of rupture), crumb firmness (F0.1 (N) - the force resisting the probe at 10% strain: Softness = 1 - F0.1), and slice thickness (mm). For most experiments, slice weight, Fmax, Dmax and F0.1 were recorded and analysed.

4 RESULTS AND DISCUSSION

The work described in this report was carried out in two major trials, covering two seasons wheats. The first trial was in June 1996, when the first attempt was made to get mixing curves from the dough probe installed in the plant bakery BP horizontal mixer. As summarised above, this attempt was unsuccessful. However, useful information comparing the properties of doughs from industrial and laboratory mixers was obtained.

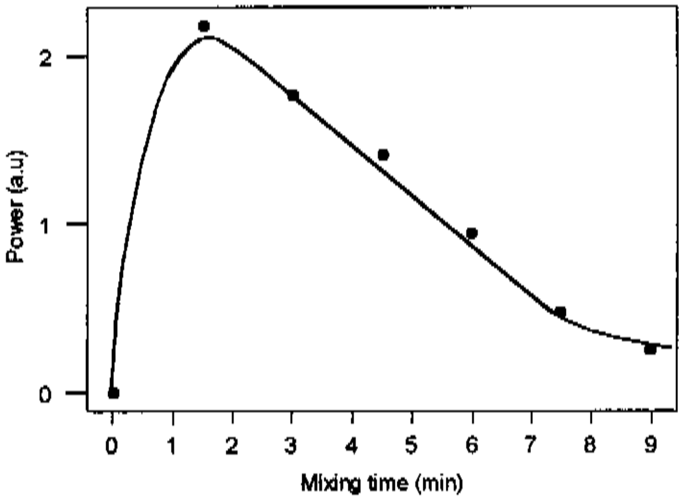
The second trial was in December 1996 when the grists being used at the plant bakery comprised flour from new season's wheat.

4.1 June 1996 trials.

4.1.1 Plant bakery mixer With the flour (protein 11.4%) being used during June, white bread doughs routinely were being mixed to 8 minutes on the BP horizontal mixer. During some preliminary trials with the probe, some dough was mixed to 10 minutes without adverse consequences and a sample was taken for microscopy. The following day, samples were taken at 1.5, 3, 4.5, 6, 7.5 and 9 minutes to give a series showing the white bread dough's development profile. For the doughs mixed up to 7.5 min, the normal mix of 8 minutes was interrupted for about 30 seconds while a sample was taken, then continued to 8 minutes. Two samples were taken at each mixing time from replicate mixes of the same white bread formula.

Dough probe Figure 1 shows a mixing curve fitted from dough probe power data (from fast Fourier analysis of the force-time readings) obtained from the mixes from which samples were taken.

Figure 1: Mixing curve fitted from dough probe power data - BP horizontal mixer.



a.u = arbitrary units

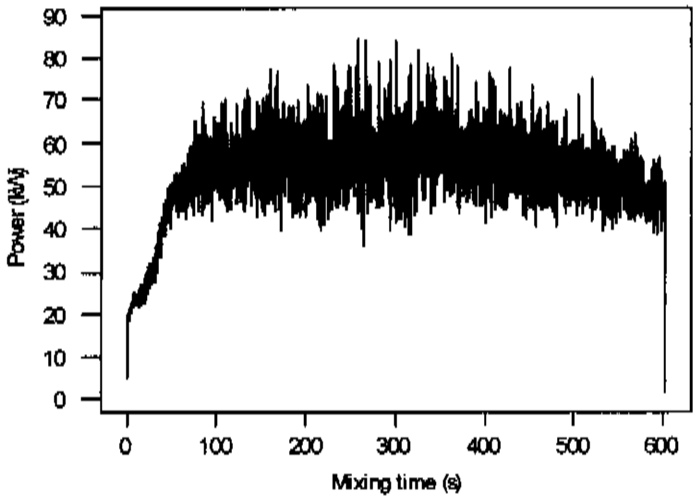
Standard Error of each mean (SE Mean) is about 0.1 a.u

Figure 1 clearly shows a false mixing peak at about 2 minutes due to the incorrect positioning of the dough probe. The fall off in the power curve after 2 minutes mixing is due to the developing dough wrapping itself around the mixer's beater bars and being in less contact with the probe. Indeed, with the probe in this position, peak dough consistency could possibly be interpreted as the point at which the power curve levels off - after about 8 minutes mixing. This is the mixing time judged by the mixer operator, and later confirmed by microscopy, as being the point of peak dough consistency and optimum dough development.

In the December 1996 mixing trials (see 4.2 below), the re-positioned probe showed peak dough consistency in agreement with expectations.

Powermix The Powermix curves tended to have a flat profile and in many cases clear peaks were hard to distinguish. A mixing curve for a dough mixed to 10 minutes, is shown in Figure 2.

Figure 2: Power consumption mixing curve - BP horizontal mixer.



This mixing curve shows a decline in power consumption after about 5-6 minutes, typical of the others that were collected, whereas microscopy (see below) suggested optimum development was occurring at about 8 minutes mixing.

Microscopy Dough micro-structure was not totally uniform in any of the samples. However, this non-uniformity also appears in dough mixed in some small-scale mixers.

The under-mixed samples taken at 1.5 minutes contained large lumps of undeveloped gluten and correspondingly large areas of starch unsupported by protein. With increasing mixing time, the gluten started forming a network. By 7.5 minutes the dough was quite well developed with the gluten forming a fine network surrounding most of the starch granules. Only slight changes in dough micro-structure were noted between 6 and 7.5 minutes, suggesting the rate of work input was insufficient for the gluten strength, which may be increasing due to yeast action. Comparison of the 9 and 10 minute samples suggested un-mixing was taking place between 9 and 10 minutes, which again could be due to the rate of work input *vs* gluten strength.

The micro-structure of the dough samples indicated optimum dough development would probably be achieved somewhere between 7.5 and 9 minutes mixing for this commercial flour and formula. From these results, the dough development time for the flour and white bread recipe used in this trial, for subsequent comparisons with the laboratory mixer doughs, was defined as 8 minutes.

Dough physical properties The dough properties, as measured on the Textron, are discussed and compared with the laboratory mixer doughs below (see 4.1.3). Dough density showed a linear decrease with mixing time, as expected with the incorporation of air during mixing.

Measurements on bread crumb A total of 15 loaves, representing doughs mixed for 8.5 (6 loaves), 9.5 (6 loaves) and 10 minutes (3 loaves), were collected from the first day's trials and measured a day later. The results showed significant mixing time effects on Fmax (crumb strength), Dmax (crumb extensibility) and crumb firmness.

The "trends" (Table 1) for Fmax and Dmax did not agree with the trends seen for two extensive laboratory mixer trials and the later, more systematic plant bakery trial (see 4.2 below) - the 10 minute mix loaf results are not as would be expected from the other trials. The drop in crumb softness with over-mixing (the optimum mixing time was about 8 minutes) is in agreement with the laboratory trials, but the later bakery trial suggested a levelling off of crumb softness with over-mixing. There are probably too few mixing time data points to expect any trends in this data.

Table 1: Crumb properties in relation to mixing time - Plant bakery BP horizontal mixer

Mixing time (min)	Fmax[1] (N)	Dmax (mm)	F0.1 (N)	Softness (N) (1-F0.1)
8.5	3.13	9.6	0.55	0.45
9.5	3.32	9.6	0.58	0.42
10	3.05	8.9	0.59	0.41

[1] Fmax is crumb strength, Dmax is crumb extensibility and F0.1 is crumb firmness at 10% strain.

A separate trial was undertaken to compare the effects of the J-Divider on the Textron dough properties. However, with the limited number of measurements we were able to make, the only consistent effect (one dough was mixed to 7.5 minutes and a second dough to 9 minutes) the J-Divider seemed to have was that dough that had passed through the divider had lower maximum tensile force values (T) and higher relaxation times (Rt). Both of these effects are consistent with the divider doing work on the dough or due to fermentation in the divider hopper. However, the expected changes in compression properties (CE increases with fermentation) and dough stickiness (TE decreases with fermentation) were not seen in the Textron measurements.

4.1.2 Laboratory trials Flour and improvers from the bakery trial were taken to Crop & Food Research in Christchurch for mixing on the 125 g variable speed mixer. Two mixing speeds were chosen - 75 rpm to represent slow mixing similar to the bakery BP horizontal mixer and 300 rpm to represent MDD mixing speeds. On the 125 g mixer a mixing speed of 150 rpm appears to be above the threshold for mechanical dough development to take place (Kilborn and Tipples 1972). Doughs were also mixed to peak dough consistency, in duplicate, at 150 and 500 rpm.

For these trials, samples were taken for microscopy and the physical dough properties were measured on the Textron. At each mixing speed, the work input to peak consistency was measured and defined as 100% of optimum. Subsequently, at 75 and 300 rpm, duplicate, full-formula doughs were mixed to 25, 50, 75, 100, 125 and 150% of optimum work input.

Microscopy The micro-structure of the dough samples from the 75 rpm set was quite different from the micro-structure of the doughs from the 300 rpm set. The 75 rpm doughs were, over all, less developed with a coarser protein network through the doughs than at 300 rpm. Indeed, by comparison with the optimally developed doughs at 150 and 500 rpm, the general effect of higher mixing speeds is a finer, more homogenous protein network.

A secondary effect was the observation that faster mixing appeared to incorporate more air cells into the doughs, particularly towards the end of mixing. The gas cell numbers and size distribution were then quantified by microscopy for the optimally developed doughs at each mixing speed. These results are shown in Table 2.

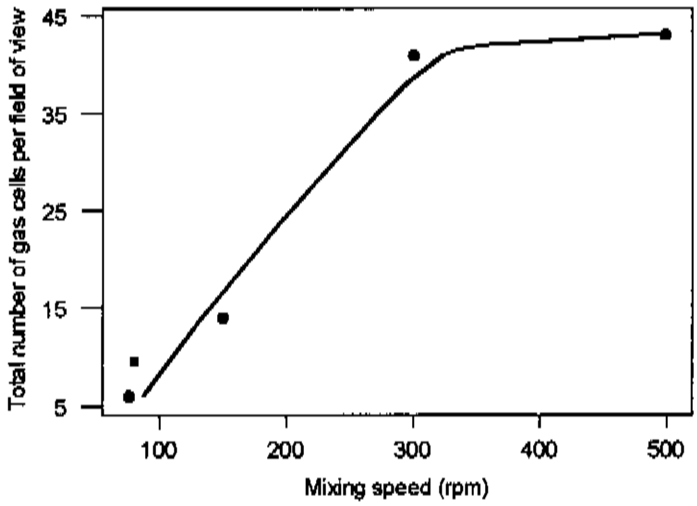
Table 2: Gas cell numbers and size distribution for laboratory doughs mixed at different mixing speeds - 125 g variable speed mixer.

Mixing speed (rpm)	0-100μm	100-200μm	200-300μm	>300μm	Total gas cells
75	3[1]	2	1	0	6
150	3	7	3	2	14
300	36	3	1	1	41
500	39	3	1	0	43

[1] Averaged results have been rounded off. Numbers are per field of view in the microscope.

When the results for the total number of cells are plotted against mixing speed (Figure 3), the effect of mixing speed is seen to be quite dramatic.

Figure 3: Effect of mixing speed on the total number of gas cells in dough mixed to peak dough consistency - 125 g variable speed mixer.



There is almost a trebling in gas cell numbers from 75/150 to 300/500 rpm. Furthermore, Table 2 shows that most of the increase in gas cell numbers is in the smallest size range (<100μm). The solid square data point (■) in Figure 3 is the corresponding average figure for

7.5 and 9 minute doughs (ie, about optimally mixed) on the BP horizontal plant bakery mixer for the same flour and dough formula. This mixer operates at 80 rpm.

Dough physical properties The dough properties, as measured on the Textron, are discussed and compared with the plant bakery doughs below (see 4.1.3).

Measurements on loaves and bread crumb Because there was only a small amount of flour left over from the dough measurement experiments, we could only do a very limited baking trial at each of four mixing speed x work input combinations (Table 3).

Table 3: Effect of mixing speed (rpm) and work input (WI) combinations on loaf and crumb properties - 125 g variable speed mixer.

Mixing speed x Work input[1]	Volume score[2]	Crumb texture	Bake score	Fmax (N)[3]	Dmax (mm)	F0.1 (N)
75 x 4.8	17	7	24	1.67	15.2	1.5
75 x 14.5	27	8	35	1.68	18.1	1.2
300 x 6.6	23	9	32	1.70	16.6	1.4
300 x 19.8	23	10	33	1.95	18.5	1.4

[1] Work inputs at each mixing speed were 50% and 150% of work to peak dough consistency.

[2] Volume, crumb and bake score are for one loaf only at each mixing combination.

[3] Crumb strength, extensibility and firmness are averages of three slices from each loaf.

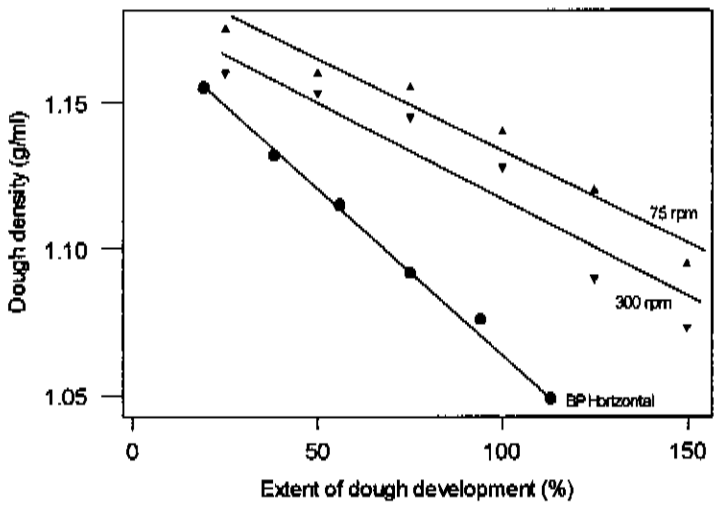
Two way analysis of variance (ANOVA) of the crumb results showed significant effects ($P < 0.05$) of an rpm x WI interaction on crumb strength (Fmax) whereby over-mixing at 300 rpm gave better much better crumb strength than the other three rpm x WI combinations. Two way ANOVA also showed that the only effects on crumb extensibility and firmness were due to work input. Crumb was more extensible, and less firm (softer), in the loaves baked from over-mixed doughs. These results are consistent with other laboratory mixer baking experiments to be reported at a later date.

4.1.3 Comparison of bakery and laboratory mixer doughs

Microscopy Comparison of dough micro-structure showed that the dough samples taken from the plant bakery BP horizontal mixer were most like the samples mixed at 75 rpm on the 125-g variable speed laboratory mixer. In addition, as shown in Figure 3, the plant bakery dough had similar numbers of gas cells. However, as shown in Figure 4 below, the plant bakery dough densities were lower, indicating that more air was being mixed into the bakery dough compared with dough from the laboratory mixers (at 75 and 300 rpm). This suggests that the average gas cell size in the plant bakery dough should be larger. Examination of the plant bakery microscopy samples showed that they had greater numbers of gas cells in the 100-200 μm range than in the 0-100 μm range.

Dough physical properties The changes in dough density, as a function of the extent of dough development, are compared for the plant bakery and laboratory mixer doughs in Figure 4.

Figure 4: Comparison of air incorporated into doughs mixed on a laboratory mixer (125 g variable speed) and plant bakery mixer (BP horizontal) as a function of the extent of dough development.

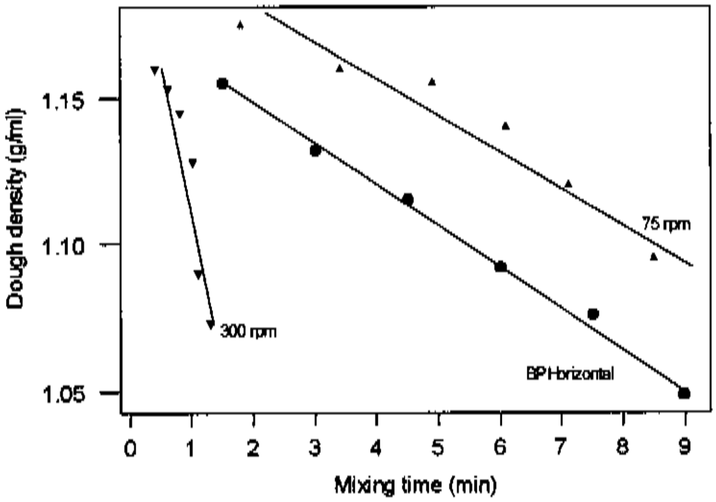


SE Mean = 0.01 g/ml

Although the 125 g mixer curves have been fitted with straight lines (the linear correlation coefficients were -0.98 ($P<0.01$) and -0.96 ($P<0.01$) at 75 and 300 rpm respectively), an alternative fit would approximate the sigmoid relationship reported by Baker and Mize (1946) for the mixing of carbon dioxide into doughs. On the mixograph, Baker & Mize found the most rapid change in dough density occurred around peak dough consistency.

These results show that at all stages during a dough's development the plant bakery doughs have more air in them than the doughs mixed at 75 and 300 rpm on the 125 g laboratory mixer. This may be a result of the air blown flour delivery systems in the bakery. When the rate of air incorporation is compared, the plant bakery mixer incorporates air at about the same rate as the laboratory mixer operating at 75 rpm (Figure 5).

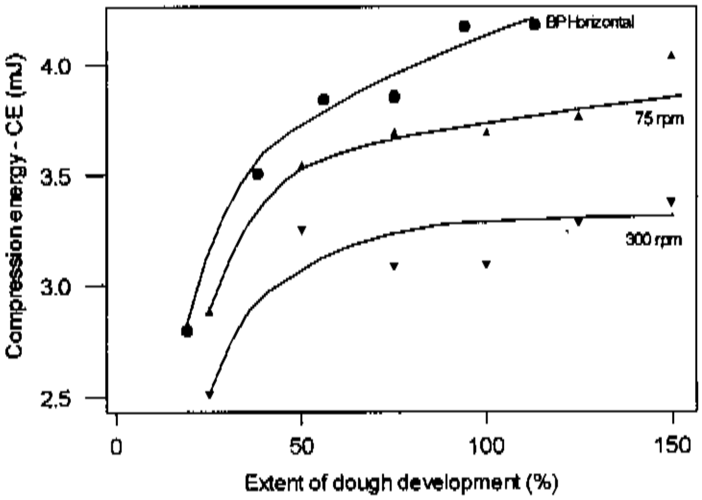
Figure 5: Comparison of the rate of air incorporation in doughs mixed on a laboratory mixer (125 g variable speed) and plant bakery mixer (BP horizontal).



Indeed, because of the very short mixing times at the higher mixing speed, dough mixed on the 125 g laboratory mixer at 300 rpm has to entrain air at a much faster rate.

The changes in other dough physical properties, as measured by the Textron, are shown in Figures 6-9.

Figure 6: Comparison of the compression properties of doughs mixed on a laboratory mixer (125 g variable speed) and plant bakery mixer (BP horizontal).

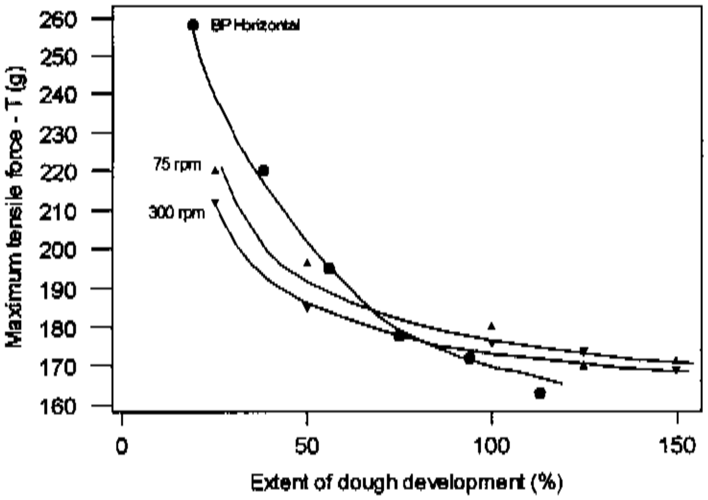


SE Mean = 0.1 mJ

Figure 6 shows that as the dough develops, its resistance to the compressing probe gets less. That is it takes longer to compress the dough to 1.5 n and the compression energy (CE), the area under the compression peak, increases. The doughs mixed on the laboratory mixer at slow speed (75 rpm) have compression properties more similar to the plant bakery dough than those mixed at 300 rpm.

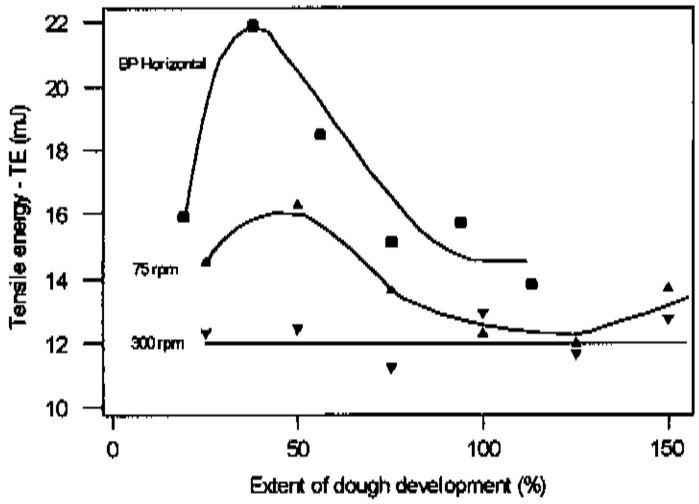
The tensile properties of the dough also change systematically as the dough develops (Figure 7). The maximum tensile force that the dough exerts on the probe as it adheres to the dough surface gets smaller. While this will be a combination of surface stickiness and internal cohesiveness, similar behaviour of the tensile peak with increasing water addition suggests that the maximum tensile force is mostly due to the dough's cohesive properties. This is supported by the results of fundamental rheological measurements being carried out in Quality Wheat CRC Program 5.

Figure 7: Comparison of the tensile properties of doughs mixed on a laboratory mixer (125 g variable speed) and plant bakery mixer (BP horizontal).



SE Mean = 4 g.

Figure 8: Comparison of the changes in tensile energy of doughs mixed on a laboratory mixer (125 g variable speed) and plant bakery mixer (BP horizontal).

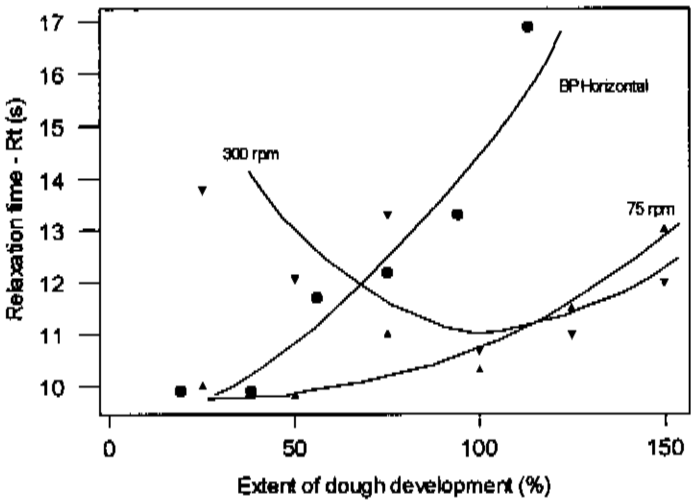


SE Mean = 1 mJ.

The area under the tensile peak in a Textron (or Instron) compression-tension curve, the tensile energy (TE), seems to relate more closely to our understanding of what a baker intuitively defines as dough stickiness (Larsen 1992). Support for this has come from recent work by Hussain et al. (1997).

The TE results shown in Figure 8, and the dough relaxation times (Figure 9) again suggest that what is happening in the laboratory mixer during dough development at 75 rpm more closely resembles the trends in dough behaviour in the slow speed plant bakery mixer. The higher stickiness of the under-mixed doughs (BP horizontal and 125 g mixer at 75 rpm) is not an unusual observation among bakers. However, among many cereal chemists there is still a persistent notion that sticky doughs result from over-mixing - without mention of under-mixing.

Figure 9: Comparison of the changes in the relaxation times of doughs mixed on a laboratory mixer (125 g variable speed) and plant bakery mixer (BP horizontal).



SE Mean = 0.6 s.

For the plant bakery dough properties in particular, dough temperature might be expected to be a confusing factor in the trends that are seen in Figures 6-9. For example, the under-mixed doughs were cold as the mixer operator was aiming for a finished dough temperature of 28-30°C. However, from previous work we've done, where doughs were mixed to constant work level but different dough temperatures (Larsen 1992) cold doughs had higher TE and lower Rt than higher temperature doughs. Both trends were highly linear. No significant trends in CE or T were seen.

Given that the 125 g doughs in the current study were mixed to approximately the same temperature at all stages of development, and the 75 rpm doughs show similar trends to the plant bakery doughs (with their big temperature differences), the effects of dough temperature on the dough property results are probably small. Indeed, for the relaxation times, the difference between the Rt's of the plant bakery and 125 g (75 rpm) doughs gets larger as the dough temperature differences get smaller. The major factors affecting the properties we measured seem to be related more to the mixing speed and the degree of development than to dough temperature. There are large differences in behaviour between the laboratory doughs mixed at the two different speeds. For example, why should the relaxation times for an under-mixed 300 rpm dough be higher than for an under-mixed 75 rpm dough?

We do not think the difference is due to the ascorbic acid/dehydroascorbic acid balance, as ascorbic acid in its reduced form, which is expected to predominate in the under-mixed 300 rpm doughs because of the very short mixing times, will decrease dough relaxation time like cysteine does. A possible explanation is that if the dough hasn't fully hydrated it might have longer relaxation times (more water in a dough decreases Rt). Then with continued mixing at 300 rpm, full hydration followed by oxidation by dehydroascorbic acid would eventually increase relaxation time along the same trend as for the 75 rpm doughs. However, the major problem with this explanation is that with the long time span of the Textron measurements, full hydration and oxidation should occur anyway - unless both processes are dependent on mixing taking place.

The trend in Rt for the 300 rpm doughs, as a function of dough development, is opposite to that observed for our mixing studies on other laboratory mixers (to be published). In these studies, a maximum relaxation time was reached - usually at about 100% dough development. Also, it is clear that with the slow speed mixing (BP horizontal and laboratory mixer at 75 rpm) a maximum relaxation time was not reached within the range of mixing studied with these full formula doughs. In a later trial (see 4.2, Figure 14) on the BP horizontal mixer, the maximum Rt was reached after about 150% development.

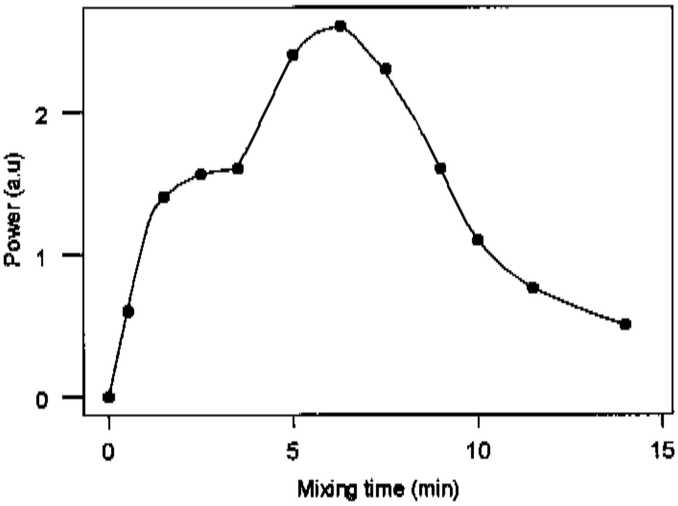
4.2 December 1996 trials.

4.2.1 Plant bakery mixer For these mixing trials, the dough probe was repositioned higher up the front centre of the mixer, to where a temperature probe had once been fitted, as outlined above (3.1.2). With the flour being used in December doughs routinely were being mixed to 8.5 minutes on the BP horizontal mixer. When mixed at 150 rpm on the 125 g mechanical dough development mixer, this flour required an optimum work input of 9.9 wh/kg - identical to the June flour (9.8 wh/kg).

Samples from white bread doughs were taken for Textron dough property measurements after 2, 4, 6, 8.5, 10, 12 and 14 minutes of mixing. These doughs were also put through the make up plant and baked so that the effects of dough development on crumb and bread properties could be assessed. During this trial a shortage of fixative meant that samples for microscopy could only be taken at 2.5, 6, 8.5, 10 and 14 minutes of mixing. Samples were also taken of doughs as they went through the make up plant after mixing.

Dough probe Figure 10 shows a mixing curve fitted from dough probe power data during a 14 minute mix.

Figure 10: Mixing curve fitted from dough probe power data - BP horizontal mixer.



The graph clearly shows a mixing peak and a hydration shoulder. Five mixing curves, from mixes ranging from 8.5 to 14 minutes, gave an average mixing time of 415 s (7 minutes) to peak dough consistency.

Powermix The peak dough consistencies interpreted from the Powermix curves ranged from about 2.5 minutes to 5 minutes for the same dough formulation, compared to 7 minutes from the dough probe curves. It was felt that the variability in the Powermix curves may be a function of the beater bar configuration, as more consistent curves were recorded from a similar mixer, with a different beater bar design, in the same bakery. Despite the better mixing curves, the second mixer's power consumption suggested peak dough consistency occurred after about 5 minutes mixing.

It is an interesting discrepancy that the power consumption measurements suggested the development peak was around 5 minutes whereas the dough probe, microscopy (see below) and the mixing times used by bakery staff suggested longer mixing times were more appropriate. One possible explanation is that the mixer power consumption decreases (ie, after about 5 minutes) because the dough is wrapping itself around the beater bars and there is less dough in contact with the mixer bowl. This would give a false maximum consistency peak because after about 5 minutes of development, the mixer motor would be consuming less power to turn the beater bars.

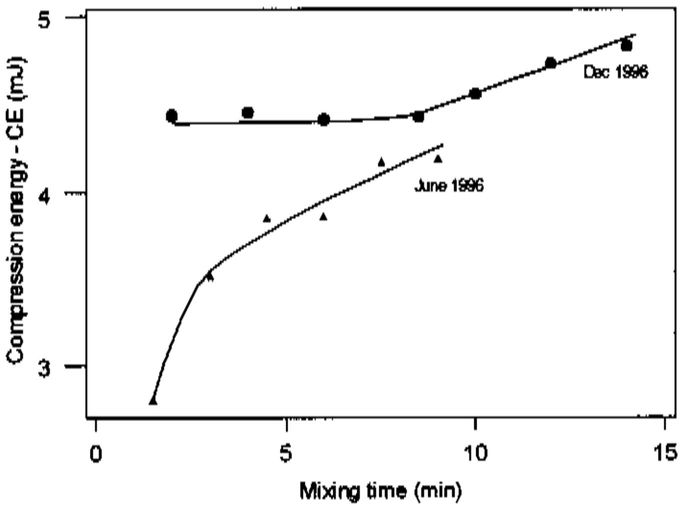
If this explanation is valid, our results suggest that with the current horizontal mixer configuration dough is being inefficiently developed during the last stages of mixing, with the result that mixing times are longer than they need be. This might also explain why not much damage is seen in dough that is mixed 100% past optimum (see microscopy).

Microscopy Because a sample wasn't taken for a dough mixed to 7 minutes, none of the samples appeared to be optimally mixed. The 2.5 minute sample showed virtually no gluten development, but by 6 minutes the gluten was starting to form an interconnected network - there were still areas of coarse, though oriented gluten, and unsupported starch. With the over-mixed samples (8.5, 10 and 14 minutes mixing), dough micro-structure suggested none were grossly over-mixed, though there was pull-back of the gluten. Based on the micro-structure, optimum development most probably occurred between 6 and 8.5 minutes mixing for this flour and dough formula.

With the doughs (from an 8.5 minute mix) that were collected from different stages of the make up plant, microscopy showed that the J-Divider destroyed some of the protein structure developed during mixing. Indeed, the J-Divider produced the most noticeable changes in the micro-structure of the dough. Before the J-Divider, the dough was generally well developed but with some suggestion of un-mixing or pull-back (the dough had been mixed for 8.5 minutes whereas the probe showed maximum peak consistency was at 7 minutes mixing). After dividing there were many areas of coarse, thick gluten strands and unsupported starch. After rounding and intermediate proof, there were still areas of coarse gluten strands and unsupported starch and it wasn't until after moulding that some of the divider damage was reversed. The majority of the gluten strands in the moulded sample were oriented, though still coarse. However, in some areas there was unsupported starch. That is, development was still not good. We have not yet looked at the effects of other dividers.

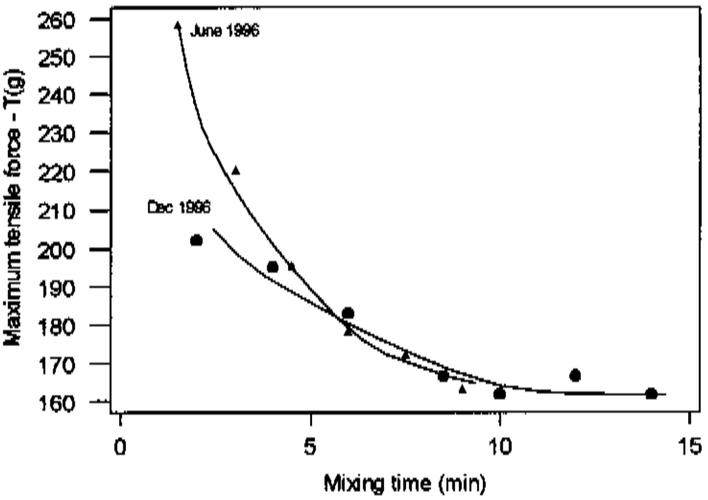
Dough physical properties The changes in dough properties with mixing, as measured on the Textron, are compared with doughs from the June 1996 trials discussed above (see 4.1.3, Figures 6-9) in Figures 11-14.

Figure 11: Comparison of dough compression (CE) properties for June and December 1996 plant bakery trials - doughs mixed on BP horizontal mixer.



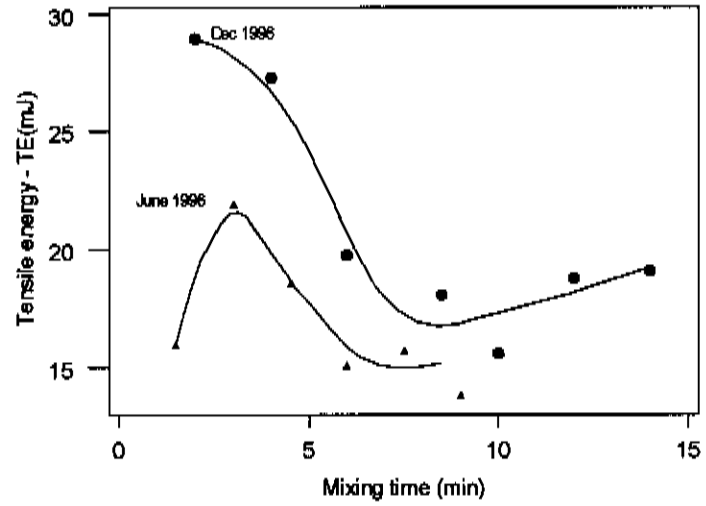
SE Mean = 0.1 mJ.

Figure 12: Comparison of dough tensile (T) properties for June and December 1996 plant bakery trials - doughs mixed on BP horizontal mixer.



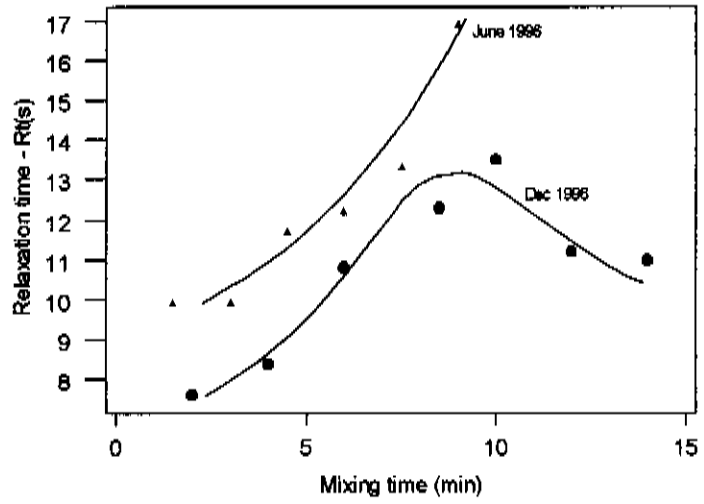
SE Mean = 5 g.

Figure 13: Comparison of dough tensile energy (TE) properties for June and December 1996 plant bakery trials - doughs mixed on BP horizontal mixer.



SE Mean = 1 mJ.

Figure 14: Comparison of dough relaxation (Rt) properties for June and December 1996 plant bakery trials - doughs mixed on BP horizontal mixer.



SE Mean = 0.8 s.

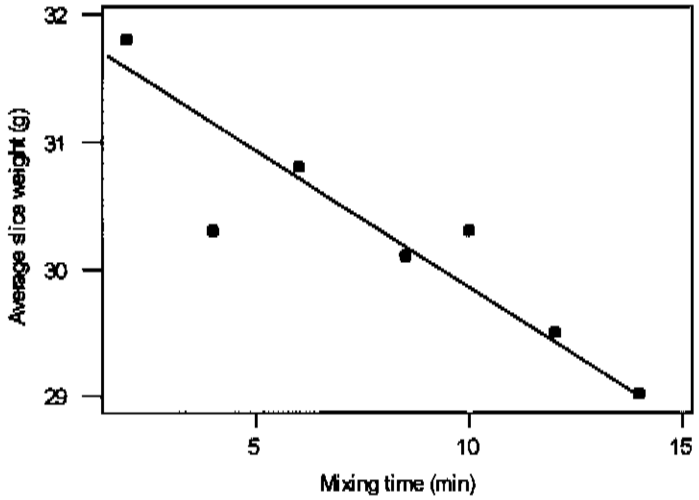
For the June trials there was not the same range of under- and over-mixed doughs as there was for the December trials. However, there appears to be quite good agreement between the two trials when the doughs have been mixed to peak dough consistency (after 7-8 minutes). That is, both flours gave doughs of similar physical characteristics when mixed to peak dough consistency, which is what a bakery wants. When comparing the maximum tensile force values (T, Figure 12: 6-9 minutes mixing) the agreement between the two trials is excellent. It is not possible to say whether or not this agreement can be attributed to the two flour's similar strength, as seen by the agreement between their mixing times (BP horizontal) and work inputs (125 g mixer).

With the data available, the doughs' behaviour diverges when comparing the properties resulting from under-mixing - in practice this is not likely to be of concern as the bakery doughs are mixed close to optimum. However for comparison, the June 1996 under-mixed doughs were quite a lot firmer according to the measurements of CE (compression energy). They were also less sticky (TE, Figure 13), and had slightly longer relaxation times (Rt, Figure 14). While these observations are consistent with there being 1% less water in the June doughs, the divergences are too big, from our experience, to be explained by water quantity alone.

Measurements on bread crumb A total of 25 loaves, representing doughs mixed for 2 (2 loaves), 4 (2 loaves), 6 (2 loaves), 8.5 (7 loaves), 10 (4 loaves), 12 (3 loaves) and 14 (5 loaves) minutes, were collected from these mixing trials and measured a day later. For the under-mixed doughs, a few kilograms of dough were removed from the mixer at the specified times and processed through the bakery. For the 10, 12 and 14 minute doughs, the whole dough was processed, after a bakers assessment that the dough would not disrupt normal production.

The trends, for the effects of mixing on the crumb properties of loaves baked from doughs mixed on the plant bakery BP Horizontal mixer, are shown in Figures 15-18.

Figure 15: Effect of mixing on the average slice weight of loaves - BP horizontal mixer.



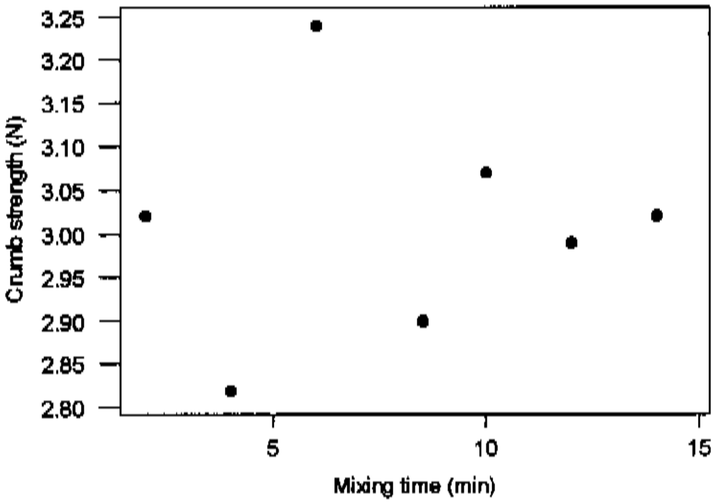
SE Mean = 0.6 g.

Figure 15 clearly shows that slices of loaves from over-mixed doughs are lighter than if the doughs were under-mixed. There could be two contributing reasons for this. Firstly, dividing is done by volume so that over-mixed, low density dough would divide into lighter portions for a given volume. Secondly, the bread from the over-mixed doughs was cooled longer because these doughs were mixed and baked first.

For crumb strength (Figure 16) it is a general observation that there is a large range of Fmax values measured for individual slices in a four-pieced loaf (A. Wilson *unpublished*). In these trials, differences in Fmax as high as 0.5 N were commonly observed between the five slices in the centre of the loaf. At least one of these slices would normally be expected to have a four-piece join running through it, and this affects the crumb properties (Morgenstern, Lau et al, 1995).

In laboratory mixing trials, where the doughs were not four-pieced before tinning up, crumb strength generally increased when doughs were mixed for longer, even when over-mixed (Quality Wheat CRC 1995/96 Annual Report, p. 20). It appears from this industrial trial that four-piecing may have removed these effects on crumb strength due to mixing - so that no trend is seen (Figure 16). However, we cannot rule out that the J-Divider is also having an effect here. We have yet to do a similar study using a different divider.

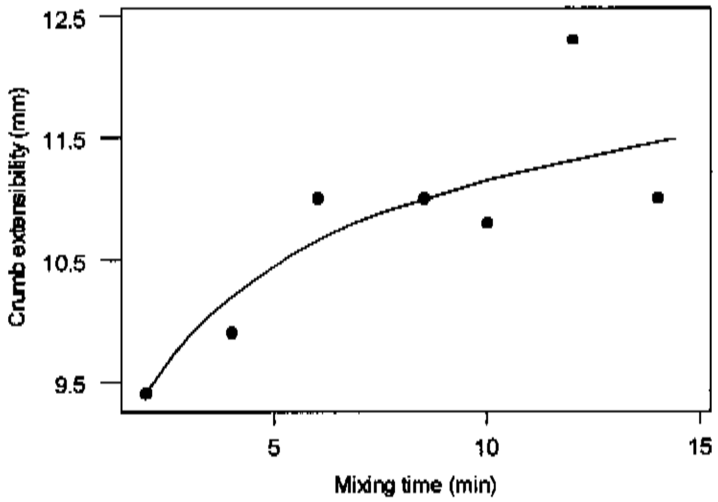
Figure 16: Effect of mixing on crumb strength (Fmax) - BP horizontal mixer.



SE Mean = 0.1 N.

The general trend for crumb extensibility (Figure 17) is similar to that found in laboratory mixer studies. That is, crumb extensibility, the extent to which the crumb will stretch before breaking, improves as doughs are mixed for longer. However most the improvement occurs in severely under-mixed doughs and there is little change about the optimum (7 minutes).

Figure 17: Effect of mixing on crumb extensibility (Dmax) - BP horizontal mixer.

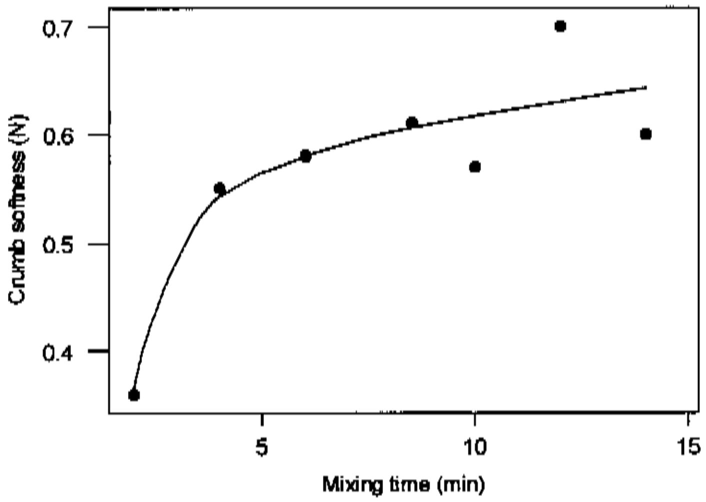


SE Mean = 0.3 mm.

For crumb softness three laboratory mixers we've studied showed a decrease in crumb softness beyond 100% development - whereas the plant bakery loaves (Figure 18) did not show this.

Over all, from a quality point of view, it is better to slightly over-mix a dough than under-mix it.

Figure 18: **Effect of mixing on crumb softness (1-F0.1) - BP horizontal mixer.**



SE Mean = 0.02 N.

Comparison of the June and December trials' crumb measurements, for doughs mixed to 8.5 minutes, shows some interesting differences:

	Fmax	Dmax	Softness	Slice Weight	Thickness
Jun '96	3.13(1)	9.63(3)	0.45(0)	26.5(0)	9.5(1)
Dec '96	2.90(5)	11.0(2)	0.51(1)	30.1(4)	10.1(2)

The standard errors for the means are shown in parentheses and relate to the last decimal place. The crumb in the December trials is weaker but more extensible and softer and the average slice thicker and heavier.

4.2.2 Laboratory trials Flour and improvers from the bakery were taken to Crop & Food Research for mixing on the 10 g, 50 g and 125 g laboratory mixers, and to Weston's R&D laboratory for mixing on the variable speed Autobake mixer (1 kg capacity) - see 3.1.1. The same recipe as the plant bakery doughs was used.

Autobake mixer Trials were done to investigate the effects of mixing speed (55, 65, 75, 85, 95 rpm) on the micro-structure of doughs developed to bakers optimum (ie, as assessed by a skilled test baker), and the properties of loaves baked from these doughs. Also, a series of mixing times (3, 4, 5 and 6 minutes) was compared with the mixing speed kept constant at 75 rpm.

The microscopy showed that as the mixing speed increased, the gluten structure became finer - in agreement with results for the 125 g mixer at Crop & Food Research (4.1.2). However, at the same time higher mixing speeds also resulted in more "chopped" (ie, broken strands) gluten, which may indicate pull-back or un-mixing. There were noticeably more gas cells after the mixer speed reached 85 rpm. Optimum development for the time series at 75 rpm, was estimated to have occurred between 4 and 5 minutes mixing.

The microscopy also suggested that the Autobake mixer, when operated at 65 rpm, gives protein structure and distribution more similar to the industrial horizontal mixer than when the Autobake is operated at faster speeds. However, we have not yet confirmed this with measurements of Textron dough properties.

The baking results are shown in Table 4. On this mixer, the image analysis crumb texture score increases (the cells become finer) as mixing speed increases, but there are no clear trends with volume, or crumb firmness and colour. Indeed, most of the loaves in the mixing speed series are of similar volume, firmness and colour, as might be expected from doughs developed to optimum (bakers assessment). However, the range of mixing speeds available on this mixer is low (0-100 rpm) and only one dough was mixed at each mixing time x speed combination, so interpretations should be treated with caution.

Table 4: Effects of mixing speed and time on loaf and crumb properties - Autobake mixer

Mixing time (min) x Speed (rpm)	Volume (ml)	Texture[1]	Crumb Firmness[2] (N)	Crumb colour (L-b*)
5.5 x 55	1615	5.4	2.5	68.5
4.5 x 65	1625	5.5	2.2	69.0
3.8 x 75	1667	7.3	2.4	68.9
3.5 x 85	1766	7.5	2.3	68.3
3.0 x 95	1652	8.4	2.3	69.1
3.0 x 75	1658	8.4	2.1	70.0
4.0 x 75	1535	6.5	2.3	68.7
5.0 x 75	1598	6.9	2.5	68.0
6.0 x 75	1677	5.4	2.2	66.8

[1] By image analysis (Coles & Wang 1997)

[2] Peak load at 10 mm compression (Westons Food Labs)

There was not good agreement between the volumes of the loaves baked from the 3.8 min x 75 rpm (loaf volume 1667 ml) and 4 min x 75 rpm (loaf volume 1535 ml) combinations.

10 g, 50 g and 125 g laboratory mixers As explained earlier (3.1.1), these three Crop & Food Research mixers have the same mixing action, being scaled versions of the same basic design (Mitchell 1984, 1989). The 10 g and 125 g mixers have variable speed capability and the 50 g mixer operates at 155 rpm. On the 10 g mixer doughs were mixed to peak dough consistency at 75, 140 and 300 rpm. On the 125 g mixer doughs were mixed at 50, 75, 150 and 300 rpm. The 125 g doughs were also baked.

The 125 g mixer mixing curves showed that the peak torque was affected by mixing speed. Higher mixing speeds gave higher peak torque. These results are compared with other dough physical properties in Table 5.

Microscopy showed that the micro-structure of the doughs from varying capacity mixers was similar at a similar speed. With respect to mixing speed, the slowest speeds had less uniform micro-structure and again it was noted that higher speeds resulted in more gas cells in the dough (eg, see Figure 3).

The dough physical properties (Table 5), as measured on an Instron, again (see also Figure 5) showed that the 125 g mixer doughs mixed to peak dough consistency at the mechanical dough development speeds (150 and 300 rpm) were significantly more resistant to compression (firmer - they had lower compression energy (CE)) than the doughs mixed at 50 and 75 rpm. The optimally mixed doughs at 50 rpm were the softest.

These results suggest that the compression properties of the dough might be linked to the protein distribution and structure as shown by microscopy. The slow speed doughs had a coarser, less homogenous protein distribution. However, it is also likely that gas cell numbers and size might influence the dough physical properties, because as dough density decreases (more air in the doughs) CE (compression energy) increases.

Table 5: Dough properties and bread quality as affected by mixing speed - 125 g variable speed mixer.

RPM	Torque (Nm)	WI (wh/kg)	CE (mJ)	T (g)	TE (mJ)	Rt (s)	Volume (score)	Texture (score)[1]
50	2.0	17.2	3.8	182	29.8	8	23.5	7.3
75	3.1	9.4	3.4	186	21.4	10	24	8.5
150	4.7	9.9	2.8	186	17.6	12	22.5	10.5
300	5.6	11.5	3.1	180	18.3	11	22.8	10.5
155[2]	-	-	3.0	175	20.4	11	-	-

[1] Subjective assessment. Texture scores in Table 4 were by image analysis.

[2] 50 g mixer.

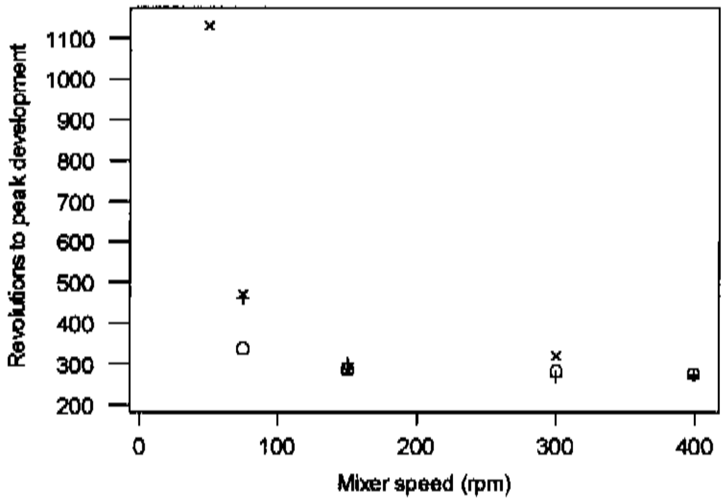
The MDD doughs (150 and 300 rpm) were less sticky, and had longer relaxation times than the slow speed doughs. There were no trends in the maximum tensile force (T) values for the doughs, suggesting little effect of mixing speed on this property when doughs are mixed to peak consistency. However, at a given mixing speed, T always decreases non-linearly with increased dough development (eg, Figures 6 and 11).

There are no significant differences in the loaf volume scores, but the texture scores are significantly different as a result of mixing speed. Like the Autobake mixer (Table 4), the crumb texture score improves as mixing speed increases. This is most probably due to the increase in gas cell numbers noted in the microscopy experiments above (see also Figure 3).

The two trials to date enable us to test the ideas of Anderssen et al. (1996) who provide evidence that the mixing of wheat flour dough has a rate-independence character. That is, a plot of the number of mixer rotations (revolutions) to peak dough development *vs* mixer speed (Mixograph - rpm) is essentially flat. Interpolating from Figure 1 of Anderssen et al. (1996), dough developed to peak at 56 rpm on the mixograph required an average of about 205 rotations, and dough mixed to peak at 92 and 122 rpm both required about 190 rotations. This work has been further followed up in a study of several different flours, with similar conclusions, and is intended for publication in Cereal Chemistry (P. Gras, personal communication).

Our results on the 125 g mixer support the contention of a rate-independence character in dough mixing, but only above a certain critical speed. Furthermore, the effects seen below this critical speed may in turn depend on whether ascorbic acid is in the dough formula. In our ascorbic acid doughs there was an exponential increase in the number of mixer revolutions needed to develop the dough below speeds of somewhere around 100 rpm. However, when there was no ascorbic acid in the dough, the rise in the revolutions required for peak dough development at 75 rpm was substantially less (Figure 19).

Figure 19: Effect of mixing speed on the number of mixer revolutions to peak dough consistency - 125 g variable speed mixer.



+ denotes June 1996 trial flour, 100 ppm ascorbic acid. Work input to peak at 150 rpm was 9.8 wh/kg.

O denotes June 1996 trial flour, no added ascorbic acid. Work input to peak at 150 rpm was 9.5 wh/kg.

X denotes Dec. 1996 trial flour, 100 ppm ascorbic acid. Work input to peak at 150 rpm was 9.9 wh/kg.

The critical speed, above which mixing becomes rate-independent, may be governed by relaxation and other processes reversing the physical and chemical changes that mixing achieves in the dough. Hence at slow mixing speeds (eg, 50 and 75 rpm on the 125 g mixer), a much greater number of mixer revolutions is required to effect the changes that define a developed dough. These considerations suggest that the critical speed may be mixer-dependent because of the different efficiencies with which different mixers develop dough.

Given the trends in Figure 19, the results of Anderssen et al. (1996, and in their subsequent work to be published) might be explained if they didn't use ascorbic acid in their dough formulation. That is, they found only a very small increase (considered to be insignificant) in the revolutions required for peak dough development at 56 rpm compared with 92 and 122 rpm. Above the critical mixing speed, our results show that the number of revolutions required for development to peak dough consistency is not dependent on ascorbic acid. Despite all these considerations, doughs mixed at low speeds still develop to a peak dough consistency and give loaf volumes the same as doughs mixed at higher speeds (Table 5).

5 SUMMARY

The project's goal is "*To be able to use a laboratory system for predicting how a flour will perform in a commercial bakery and to commercially use a measure of dough development for process control*".

The work outlined in this report demonstrates progress in both the science needed to achieve the project's goal, and our understanding of the relationships between laboratory and commercial dough mixing.

Science progress

In order to achieve the project's goal, we've made good progress in directing the science along the following lines:

■ *Establish means of measuring mixing requirements in laboratory and commercial dough mixers.* Methods for measuring mixing requirements in laboratory mixers were already well established. However, reliable means were still needed for some industrial mixers. This work has shown that the dough probe will measure dough development in the large horizontal mixers commonly used in Australia.

The probe provides an alternative to power consumption measurements that work reliably on some slow speed mixers but not on others. Including work done before the CRC, the dough probe has been proven to work on both high speed and low speed industrial mixers. This feature would provide a consistent means of measurement for companies using both types of mixer.

Experiments are intended to compare the dough probe and power consumption curves for sensitivity to processing changes (flour types, dough formula changes).

■ *Establish means of defining and comparing dough properties.* The microscopy and dough physical property (Textron) methods described in this report had been previously described. However, this work has, for the first time, used dough property measurements to define and compare doughs from small scale and industrial scale mixers. More importantly, the measurements have been done on full-formula doughs which makes the measurements directly applicable to an industrial bakery. With the Textron, measurements can be done on-site.

More work is needed to confirm whether dough property measurements on a small scale can be used to predict measurements on plant bakery doughs.

- *Define what is happening in laboratory and commercial mixers as dough develops.* This has been achieved using a combination of mixing curve measurements, microscopy descriptions of dough micro-structure and dough physical property measurements using the Textron. The results have enabled direct comparison between different trials and different mixers.

- *Establish the relationships between the two types of mixers (laboratory and commercial).* This work has shown that we now have the means to relate doughs mixed from 10 g flour up to 350 kg flour. Variable speed mixing capability has proven to be a valuable tool in looking for agreement between the two types of mixer.

- *Understand what effects the make up plant has on dough and product quality.* Some initial experiments have been carried out successfully using microscopy to show how the make up plant changes dough structure. Textron measurements also suggest a change in one of the properties (maximum tensile force, T).

Significant findings

- A dough probe, which measures changes in the consistency of dough as it is mixed, gave reproducible mixing curves when installed in a slow speed industrial horizontal mixer. However, correct positioning of the probe is essential for it to maintain proper contact with the developing dough - which tends to wrap itself around the mixer's beater bars. Adjustments were made to the mixing times in the plant where the probe was installed. This probe has now been shown to work for both high speed and slow speed mixers of the types commonly used by plant bakeries in Australia and New Zealand.

- Measurement of power consumption was trialed in conjunction with the dough probe. However, more work has to be done to make a definitive comparison of both methods for process control in industrial mixers, so we can interpret the mixing curves in terms of dough development and quality.

- Dough micro-structure is not uniform in doughs from the industrial horizontal mixer. However, this non-uniformity also appears in doughs mixed in some small-scale mixers. Because it is on a micro-scale, this non-uniformity is expected to average out and not make a significant contribution to the variation usually found in larger scale rheological and physical dough property data.

The micro-structure of dough samples mixed to peak dough consistency depends on mixing speed. The general effect of higher mixing speeds is a finer, more homogenous protein network. A secondary effect, but with the most noticeable influence on product quality, is that faster mixing incorporates more air cells into dough and gives finer crumb textures.

- It was encouraging that laboratory mixers can be shown to "correlate" with industrial mixers and that the agreement between laboratory and industrial mixers can be fine-tuned by using variable speed mixing.

Comparison of dough micro-structure showed that the dough samples taken from the plant bakery BP horizontal mixer (80 rpm) were most like the samples mixed at 75 rpm and 65 rpm on the 125 g variable speed and Autobake laboratory mixers respectively. The plant bakery mixer also gave doughs with similar numbers of gas cells, and entrained them at a similar rate, to the 125 g mixer doughs at 75 rpm. However, because the plant bakery dough densities were lower, average gas cell size in the plant bakery dough was slightly larger.

Comparison of dough physical properties, and how these properties are affected by dough development, showed that the changes in dough properties for doughs mixed at 75 rpm on the 125 g mixer more closely resembled the trends shown by the plant bakery mixer than doughs mixed at 300 rpm on the 125 g mixer. Even so, there were still absolute differences in the values for the different dough properties at 100 % development on different mixers and at different mixing speeds - despite the dough recipes being exactly the same.

The Textron dough property with the closest agreement between doughs developed to 100% was the maximum tensile force (T). This is also what is observed with laboratory mixer studies (to be published) - in two studies to date, doughs with identical recipes developed to peak dough consistency on dissimilar mixers (spiral and high speed) had the same T values.

■ In loaves from the industrial plant, the crumb properties of extensibility and softness both showed improvement as the extent of dough development increased in severely under-mixed doughs. Crumb strength was not affected, contrary to laboratory mixer studies, and we attribute this difference to the four-piecing of the plant bakery doughs. In loaves from two different types of variable speed laboratory mixer, crumb texture became finer as mixing speed increased.

■ The dough make up plant in the industrial bakery was shown to affect the dough structure developed during mixing. The J-Divider produced the most noticeable changes in the micro-structure of the dough. Indeed, the divider destroyed some of the protein structure developed during mixing, resulting in many areas of coarse, thick gluten strands and unsupported starch. It wasn't until after moulding that some of the divider damage was reversed. We do not know whether this damage reversal is a function of time (dough relaxation) or moulding.

■ Our results on the 125 g mixer support the contention of a rate-independence character in dough mixing, but only above a certain critical speed. This critical speed may be governed by relaxation and other processes reversing the physico-chemical changes that mixing achieves in the dough. The effects seen below this critical speed may in turn depend on whether ascorbic acid is in the dough formula.

6 IMPLICATIONS FOR INDUSTRY

This work is forcing yet another re-think of how to describe and compare dough development. It is clear that doughs mixed to peak dough consistency at a range of mixing speeds (on the same mixer) are not alike in all respects, and can differ in their physical, chemical and processing properties. If we observe these differences on the same mixer, it is little wonder that industry has problems standardising production and quality from mixers of different design and capacity (eg industrial scale *vs* laboratory scale).

There are several implications for industry to consider:

- Agreement between dough mixers of different design and capacity can be improved and fine-tuned if the mixers have variable speed mixing capability. R & D laboratories should take this into consideration when designing or ordering new mixers. This raises the possibility that there could be better agreement between similar types of mixers in plant bakeries (assuming that the rest of the plant is similar) if there was capability for variable speed mixing on industrial mixers. The latter might also allow bakeries to improve crumb texture in products made from single-pieced doughs.

- A dough probe has now been shown to give interpretable mixing curves for slow speed mixers of the types commonly used by plant bakeries in Australia and New Zealand. However, more work has to be done with both the dough probe and power consumption measurements of dough consistency to determine their relevance for process control in industrial mixers.

- The current work has established that damage to the dough structure occurs in the J-Divider. However, further experiments are needed to determine if the micro-structural damage has implications for product quality. We also need to find out what mechanisms allow the structure to recover.

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