QUALITY WHEAT
CRC PROJECT REPORT

Project No: 1.2.1

Frozen Bread Dough Production

Dr Steven Zounis¹ and Dr Ken Quail¹,²

¹. BRI Australia
². Quality Wheat CRC Limited

Date: February 2000

CONFIDENTIAL
(Not to be copied)

Quality Wheat CRC has taken all reasonable care in preparing this publication. Quality Wheat CRC expressly disclaims all and any liability to any person for any damage, loss or injury (including economic loss) arising from their use of, or reliance on, the contents of this publication.
Quality Wheat CRC Report

Title Frozen Bread Dough Production

Project No. 1.2.1

Prepared by Ken Quail
Steven Zounis

Date February 2000
1. Executive Summary

Test equipment and a test method were established for the evaluation of frozen bread dough. This included the development of a jacketed spiral mixer to achieve finished dough temperatures under 20°C; and a blast freezer with a freezing rate of up to –0.8°C per minute. A test method has been developed to evaluate frozen dough products and this is available as an industry service.

A rapid storage test has also been developed to reduce the time required to evaluate frozen storage. This reduces the time taken to complete a four month storage trial to less than three weeks. The approach taken is to cycle doughs between –10 and -20°C through a time course. This encourages water migration and ice crystal growth which appear to be the major cause of the decline in bread quality during frozen storage.

An assessment of ingredients and flour types has lead to a number of recommendations on process and dough formulation to optimise frozen dough production. However this study found that bread quality was poor when dough was stored for more than three months. We recommend that with current technology businesses do not plan for frozen storage longer than 10 to 12 weeks. The major loss of bread quality appears to result from loss of yeast activity. This does not appear to be preventable with current technology.

Electron microscopy was used to study the changes in dough structure during frozen storage. It was possible to identify the increase in ice crystal size and the degree of disruption this caused to the dough structure. This method confirmed that temperature cycling resulted in similar changes in the dough to continuous storage. From measurements of dough rheology it appears that the disruption to the gluten structure does not significantly reduce its strength.

Perhaps the clearest outcome of this study is the impact of temperature cycling on dough storage. Changes in temperature during storage have a major impact on quality. To have any hope of marketing frozen dough successfully the chain from production to bake-off requires very stable temperatures.

Outstanding work to be reported from this project will include the assessment of croissants, changes in protein composition during storage and a PhD thesis to be prepared by Steven Zounis.
2. Background

2.1 Markets
Frozen dough production is big business in the US with a retail value of over 5.0 billion dollars for frozen dough products in the US per annum (Al-Eid, 1993). It is also popular in Canada and Japan accounting for 7% of white bread production in these countries (Newberry, 1995). In France, it is estimated that over 30% of commercial baguettes are now baked from frozen dough (Le Bail, 1999).

Use of frozen dough in the US is mainly to service in-store supermarket bakeries. The frozen dough is manufactured in a large central bakery and distributed to supermarkets. The shelf life is usually less than one week. The main advantages of this are:

- less space required for the instore supermarket bakery
- less skills required of the instore bakery operation, particularly with pre-programmed defrosting and baking.
- fresh bake off.
- consistency of product between supermarkets within a chain.
- economics of scale for production appear to overcome increased costs of transport and storage

In 1991, 50% of in-store bakeries in the US used frozen dough for their bread production (Bergland et al, 1991). Growth of this market is still continuing according to Addo (1997).

2.2 Australia
The frozen bread dough market has not been very large in Australia and in 1999 none of the major baked goods manufacturers were using this technology. Our industry has a different structure to many overseas markets with a mix of bakery types. Production from scratch or the use of par baked products has replaced the need for frozen bread dough.

One factor limiting frozen bread dough has been their poor quality and limited shelf life. With low population density it was felt that to be economically viable to establish large production facilities export markets would be required. To achieve viable exports it was felt that a frozen shelf life of greater than three months was required. This was the main argument for developing this project.

Frozen pastry products have been far more successful and these account for the majority of retail sales in this product category. These products produce high quality finished goods and have shelf lives over seven months. These products are also more labor intensive to produce in small bakeries compared to bread and therefore bakers find more value in using the frozen product. Most pastry products are small and thaw quite rapidly. This contrasts to larger bread products, which are slow to thaw, often requiring 12 hours for the best results which is highly inconvenient and allows little response to demand.
Frozen dough production

One chain of specialist bakery products, Delifrance, has used frozen bread and pastry products very successfully. This business operates with a short frozen shelf life and selects products that are suited to frozen production.

2.3 Frozen Storage
The frozen shelf life bread of dough is limited by the loss of yeast activity, and deterioration of the gluten structure.

2.3.1 Yeast
Loss of yeast activity is the major problem in frozen doughs (Holmes and Hoseney 1987). It is the most single studied ingredient in frozen bread dough (Bruinsma and Giesenschlag 1984; Holmes and Hoseny 1987). Yeast cells die both during the initial freezing operation and subsequent deep frozen storage (Cauvain 1982). Ice crystals that physically puncture the outer membrane of the yeast could cause the loss of yeast viability. Current research interest has focused mainly on the isolation and development of a freeze-tolerant strain that retains the baking activity of the yeast (Gelinas et al 1989). Very little is known as to why one yeast strain is more resistant to damage during freezing than another. Freeze-tolerant yeast strains have been discovered, but these however, are not yet totally satisfactory for use in frozen dough baking (Hatano et al 1996).

2.3.2 Gluten structure
The gluten structure in frozen dough appears to be weakened by the physical damage of ice crystals and the release of glutathione from dead yeast cells.

2.4 Project objectives
The current project was developed to investigate the viability of extending the shelf life of frozen bread dough products.

The following sub objectives were developed.

1. Establish methods for the evaluation of frozen bread dough. This included the following:
   - Test baking method to assess dough performance
   - A yeast test to assess yeast activity
   - Microscopy methods to assess the impact of ice crystals
   - Rheological tests to measure changes in dough function
   - Protein analysis to assess changes in protein structure

2. Establish a rapid storage method to assess the impact of ingredients and processing on frozen storage life.

3. Assess the effects of processing and ingredients on the frozen shelf life of bread dough.
2.5 Literature Review

For a more detailed literature review from this project, please see the PhD thesis prepared by Steven Zounis.

Bread from one week frozen storage on the left and 16 weeks frozen storage on the right. These loaves were baked from 550g dough pieces. Loaf volume forms an objective means of measuring the effect of storage. However there are many other bread faults that occur. The loss of crumb texture is the most significant and in the above case of 16 weeks storage the crumb was hard and would be unacceptable to consumers. The bread baked after one week storage was almost comparable to a fresh product.
3. Results

3.1 Bread Making Process

Most commercial frozen dough production utilises rapid bread making processes and this has been supported by a number of researchers Cuavain 1996, Lorenz and Bechtal, 1964). Extended periods of fermentation before freezing reduce bread quality. It is believed that activation of yeast reduces its stability during subsequent frozen storage. It is therefore important to minimise the time from mixing to freezing. The Chorleywood process has been suggested by Cuavain 1996 as a suitable rapid process. Results from this study indicated that the Chorleywood process should be considered for frozen dough production.

3.2 Ingredients

3.2.1 Flour

Most commercial bakery formulations have added gluten to achieve high dough strength for frozen dough production. Strong flour types are recommended to complement this.

The following four flour types were compared in this project.

- Commercial bakers flour 11.2% protein
- Commercial bakers flour 12.0% protein
- Commercial bakers flour (12%) + 2% commercial gluten
- Commercial Bakers flour (12%) + 4% commercial gluten

It was found that the bakers flour with 2% added gluten gave the best result however this improvement was not significantly different to the bakers 12% flour (Fig 1). The bakers flour at 11.2% did not perform as well as the stronger bakers flour and when 4% gluten was added it gave the poorest results. When 4% gluten was added the dough was difficult to develop adequately at a low finished dough temperature, and was difficult to machine. It appears that flour with excessive strength is undesirable.
Frozen dough production

Figure 1 Effect of flour on loaf volume for frozen doughs.

3.2.2 Yeast

It is generally recognised that frozen doughs require higher yeast levels (Casey and Foy, 1995). This is to account for the loss in yeast activity that occurs during initial freezing and frozen storage. The loss of yeast activity can be measured using a fermentagraph.

This project developed a fermentagraph method for the measurement of yeast activity in the frozen doughs. The dough was thawed as for baking and then a 200 g sample cut from the dough piece. The dough was molded and placed in the fermentagraph chamber. The fermentagraph result after one hour was used as the measure of yeast activity as this was in keeping with the proving requirements when preparing bread.

It was found that the yeast level needed to be adjusted to suit the expected shelf life (Fig 2). For frozen shelf life of up to 7 days this may require an increase of 20%. From 7 to 30 days an increase of 50% is recommended. At greater than 30 days an increase in yeast level of 100% is recommended. At a compressed yeast addition of 3% of flour weight, for 3 to 7 days the yeast level would be increased to 3.6%; for 7 to 30 days it would be increased to 4.5% and for periods of frozen storage greater than 30 days 6% yeast would be used.

Fig 2 The effect of yeast level on loaf score. Although loaf volumes may have been high, the crumb structure was very open and the bread scored lower.
Frozen dough production

Delayed yeast addition was found to give some improvement in frozen dough performance. We recommend that the yeast is added when mixing is 80% completed, this is enough to ensure that it is mixed evenly through the dough.

Yeast type
There are some yeasts available that are considered more suitable for frozen dough production. These are not marketed in Australia and we were not able to test them. Discussions were held with the CRC for Food Innovation and Mauri Yeast early in the project. The CRC was considering the development of yeast strains with increased cryoresistance. We are not aware that they have had any success with this program.

This project used compressed yeast for all trials. There would be no reason to consider liquid yeast any less suitable. Dried yeast is considered more fragile than compressed yeast due to the drying process, its activity is reduced by cold shock during mixing and it also has some glutathione. As a result dry yeast is not generally recommended for frozen dough and it was not tested in this project.

3.2.3 Chemical leavening
A trial was conducted with chemical leavening agents to partially replace yeast activity. Advice was sought from Albright and Wilson on which agents to test. The initial trial included the slow release Calcium Acid PyroPhosphate (CAPP) balanced with sodium bicarbonate (soda). Different levels were tested to replace yeast in fresh doughs. Yeast levels ranged from 1 to 3%, CAPP from 0.9 to 2.7 and soda from 0.5 to 1.5% in an RSM design. Chemical leavening seriously depressed loaf volume, probably due to its effect on dough pH. It is also noted that the release of CO₂ is premature in the bread making system. The trial was not tested in a frozen dough system.

To overcome the pH and premature release of CO₂, an encapsulated chemical leavening agent was tested (CAP-SURE from Balchem Corporation, Slate Hill NY, USA). This was also tested in fresh doughs with yeast levels of 1, and 2%. The encapsulated product did not appear to contribute to the gassing power of the dough and the encapsulation produced a strange speckiness in the final bread, which indicated that it did not dissolve completely (Fig 3).

![Control baked with 3% yeast and no chemical leavening. Trial 1 included 1% yeast and 0.65% CAP-SURE/0.9% CAPP, and Trial 4 was 2% yeast and 0.65% CAP-SURE/0.9% CAPP](image-url)
3.2.4 Gluten Modifying Agents
Oxidising agents including ascorbic acid, potassium bromate and azodicarbonamide (ADA) are all commonly included in frozen dough formulations. These ingredients increase dough strength and processing tolerance. Of these ingredients only ascorbic acid is permitted for use in Australia. Recommended levels range from 100 to 150ppm. Higher levels of ascorbic acid results in tough doughs that are difficult to machine. This problem may be exacerbated by the use of strong flours with added gluten.

Reducing agents such as cysteine and sodium metabisulphite are not recommended for frozen doughs as there is too much time for their action and they weaken the dough structure for baking. This means that these agents cannot be used to improve machining of over-strong doughs, this places a limitation on the use of very strong doughs where machining is a problem.

All formulations in the present study contained 100ppm ascorbic acid. A trial was conducted to assess the impact of 30ppm of potassium bromate, which is known to improve dough tolerance during baking. The bromate increased the shelf life for approximately 2 to 4 weeks. Other studies have found further improvement in shelf life with higher levels of bromate (De Stefanis, 1995). However as stated, bromate is not permitted for use in Australia.

3.2.5 Fat
Fat is considered highly effective in the reduction of water movement and ice crystal growth. This is clearly apparent for pastry products where much longer shelf life is achievable when compared to bread.

A trial was conducted to assess the difference in fat levels. Up to a fat level of 8% we did not achieve any improvement in frozen shelf life (Figs 4 and 5). Adding fat at more than 3% changed the nature of the bread product. At the conclusion of this work we determined that the product must be defined and the fat level matched to it. For example if you are making a baguette which traditionally has no fat then it is better to work with no fat or perhaps less than 1% for the frozen product to gain some extra stability. Going above this level will change the nature of the product, ie it will no longer have the characteristics of a baguette.

![Fat levels graph](image)

*Fig 4Comparison of 1 and 4% fat levels on the frozen shelf life of bread dough*
Fig 5 Comparison of a low fat and sugar dough to one prepared with 10% fat and 10% sugar. The lower volume of the high fat and sugar can probably be explained in this case by the equivalent yeast levels used for the two doughs. High and fat and sugar reduces yeast activity.

3.2.6 Other ingredients
For other ingredients we recommend similar levels to standard rapid doughs. This includes salt, sugar and amylase. It may be better to use maximum quantities of emulsifiers such as SSL and DATEMs as these increase dough tolerance without toughening up the dough. Of these ingredients only SSL was tested from 0 to 0.4% with an improvement in loaf quality consistent with what is experienced in fresh bread production.

Anti-freeze proteins
An original objective of this project was to evaluate the use of some unique antifreeze proteins that can reduce ice nucleation. This reduces the tendency to form ice crystals, which are considered to cause the most damage to yeast cells and possibly the gluten network.

Commercially available antifreeze proteins were considered too expensive to be considered viable. A novel source of protein which was to be developed by CSIRO was not available when this report was prepared.
3.2.7 Recommended formulation

The following formulation is recommended from the outcomes of this research for a frozen shelf life of between 1 and 3 months.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flour (12% protein)</td>
<td>100%</td>
</tr>
<tr>
<td>Salt</td>
<td>2%</td>
</tr>
<tr>
<td>Yeast compressed</td>
<td>5%</td>
</tr>
<tr>
<td>Gluten</td>
<td>2%</td>
</tr>
<tr>
<td>Sugar</td>
<td>1%</td>
</tr>
<tr>
<td>Fat (hydrogenated)</td>
<td>2%</td>
</tr>
<tr>
<td>SSL</td>
<td>0.4%</td>
</tr>
<tr>
<td>Ascorbic acid</td>
<td>100ppm</td>
</tr>
<tr>
<td>Ammonium chloride</td>
<td>0.05%</td>
</tr>
<tr>
<td>Fungal amylase</td>
<td>(depends on source –level as for fresh dough)</td>
</tr>
<tr>
<td>Water</td>
<td>to suit flour, reduce by 2% from fresh dough</td>
</tr>
</tbody>
</table>

3.3 Dough Mixing

Fermentation periods before freezing have been shown to reduce the shelf-life of frozen doughs for bread production (Merritt, 1960). It appears that once yeast is activated it is more susceptible to damage by freezing. Yeast activity can be minimised by reducing finished dough temperature and processing time prior to dough freezing. Rapid dough processes have been selected to reduce processing times.

A feature of rapid dough systems is that they require that the dough is fully developed in the mixer. However there is little information available on the development of dough at low temperatures. We hypothesize that at lower temperatures the mixing requirement is greater to achieve the chemical reactions required for dough development. We also predict that mixing is critical for frozen doughs where the gluten structure may be weakened by frozen storage. Optimum mixing is recognised to result in a more tolerant dough structure, which would be expected to enhance frozen dough performance.

A more detailed report on dough mixing is attached as Appendix 1. The mixing report below is essentially a summary of the more extensive report.
3.3.1 Mixer

To achieve dough temperatures below 20°C it was essential to chill the flour and use a jacketed mixer.

An Eberhardt spiral mixer was adapted to take a water/glycol bath. This enabled the mixing of doughs with finished dough temperatures below 15°C. This mixer allows excellent control of dough temperatures and is highly suited for test baking 3 to 5kg doughs. This was a useful development in its self and we are unaware of any commercial jacketed spiral mixers. However this style of jacketed mixer would be difficult to adapt to a production environment as it is difficult to clean.

3.3.2 Mixing requirement

It was found that work input or mixing time had to be increased as dough temperature decreased. This relationship was linear as was the increase of dough temperature monitored during dough mixing. To achieve a finished dough temperature of 18°C, the mixing time had to be increased by up to 80% to achieve similar dough development to a dough finished at 30°C. For example if the dough required 8min mixing with a dough temperature of 30°C, it would require approximately 14min if the dough temperature is reduced to 18°C.

3.2.3 Effect of mixing on shelf life

Five dough formulations were prepared, each with the same flour. The TTP at a finished dough temperature of 18°C was approximately 12min. Each formulation was prepared using two mixing times on the Eberhardt mixer with finished dough temperatures of -18°C. Each dough was prepared in triplicate and baked after 2, 4, 8, 12, 16, 20 and 24 weeks of frozen storage. The two mixing times selected were 12min to represent well developed dough and dough with 25% less development or 9min mixing. Twenty five percent less than TTP was selected from an estimate of undermixing observed in industry. Doughs 1 and 2 resulted in poor bread which did not produce viable loaves after 12 weeks of storage with either mixing time.

Loaf volume results from doughs 3, 4 and 5 produced similar trends showing the 12min mixed dough to consistently achieve higher loaf volumes than the undermixed dough (fig 6).
3.2.4 Adding Ice

Ice is often added in place of water to reduce dough temperature. For commercial frozen dough production it was observed that large amounts of ice were being used and we tested from 20 to 60% ice substitution. Measurements of mixing time indicated that the mixing time increased with ice addition significantly more than was accounted for by the change in dough temperature.

This makes mixing with ice addition appear very inefficient. The mixer must expend both time and energy to melt the ice before the dough can hydrate and dough development can begin. Where ice has been used to lower finished dough temperatures it has probably been at the expense of dough development. It is recommended that ice is only used to reduce the temperature of the dough water, being allowed to melt before mixing commences.

3.2.5 Finished dough temperature

A trial to determine the effect of dough temperature was prepared using the Eberhardt mixer to produce doughs of different temperatures at equivalent dough development and a Tweedy dough with a finished dough temperature of 30°C. When dough mixing had been completed the doughs were processed immediately before freezing. Once frozen, the dough volumes were measured using water displacement. The average volume of the dough mixed to a finished dough temperature of 18°C was 490cc, for the Eberhardt dough mixed to 30°C it was 550cc and for the Tweedy dough it was 510cc. It appears that the higher finished dough temperatures resulted in larger frozen volumes due to greater yeast activity and the longer time taken to freeze the dough. The higher volume translated to higher initial bread volume (Fig 7). The higher temperature doughs had an advantage when the frozen storage was under 8 weeks, however at longer storage times the 18°C dough gave higher loaf volume and better yeast activity than the 30°C doughs (Fig 8). The Tweedy dough appeared to perform quite well and further consideration should be given to this process for frozen dough production, especially when working at under 8 weeks storage.
Frozen dough production

These results certainly suggest that for short frozen shelf life it may be better to work at higher dough temperatures. This appears to allow higher initial dough volume. It is certainly a lot easier to produce doughs at this temperature.

Both the fermentagraph and loaf volume results indicate that the yeast activity of the dough prepared at 18°C remained higher over the 16 week period which supports earlier studies and the rationale behind working with low dough temperatures.

Additional work in a separate trial to study the effect of finished dough temperature indicated superior performance for dough mixed to 18°C compared to dough finished at 31°C on the Eberhardt mixer. In this case the bread at 14 weeks storage had superior volume, but more importantly the total score was higher (Fig 9).

Fig 7 Effect of finished dough temperature on frozen shelf life, including comparison between Tweedy and spiral mixers for loaf volume

Fig 8 Effect of finished dough temperature on frozen dough shelf life including comparison between tweedy and spiral mixers on fermentagraph

Fig 9 Bread prepared with different finished dough temperatures and stored frozen for 14 weeks before baking off. On the left the dough was finished at 31°C and on the right 18°C.
Frozen dough production

For longer shelf life it is clearly essential to work with lower dough temperatures. From this project, we recommend a finished dough temperature of less than 22°C as a pragmatic compromise as it is so difficult to achieve finished dough temperatures under 20°C with good dough development.

A further consideration is that in commercial practice larger doughs may take longer to process due to their size. This would need to be taken into consideration if working with higher dough temperatures even on a Tweedy mixer as there may be more time available for yeast activation.

3.4 Dough dividing and makeup

This project worked with frozen dough pieces of 550g. This was considered the maximum dough piece size suitable for extended shelf life. Larger dough pieces take too long to freeze and thaw.

The water level for frozen dough is often reduced to overcome stickiness during dough make up, this may be a reduction of between 2 to 4%.

It is important to minimise the time from mixing to freezing and to avoid temperature gain during these stages.

3.5 Freezing

3.5.1 Blast Freezer

Work was initiated with a liquid nitrogen freezer. However the freezer was designed for very fast chilling and reduced the temperature of the dough pieces very quickly. The major problem with this facility was high air velocity, which caused excessive drying of the dough surface and very rapid cooling. Samples baked from the cryogenically frozen bread doughs were very poor and we suspect that the freezing rate was too high resulting in excessive damage to the yeast. The freezing rates were also extremely variable between locations in the freezer. The design of the freezer, which was on loan, did not allow us to adjust the air velocity.

At this stage a blast freezer was designed and constructed using mechanical freezing. The freezer was designed to give even air flow at a velocity of 6.5 m/sec. The freezing temperature is variable between -5 and -35°C. The freezer was constructed by a Sydney refrigeration company (R & E Engineering) and has proved to be effective and reliable. This is available for industry to conduct frozen trials at BRI.

3.5.2 Freezing rate

The freezing rate achieved in the mechanical freezer set at -35°C was approximately -0.8°C per minute. The changes to the dough during freezing are shown...
Frozen dough production

in the series of photos which show a cross section of the dough (Fig 10). The soft core gradually disappears as the dough is frozen solid. During freezing the aim was to minimise the time in the blast freezer whilst ensuring the dough is adequately frozen. When frozen to a core temperature of between 0 and -5°C, a soft core of approximately one centimeter diameter remained. When the dough was transferred to the storage freezer set at -18°C the dough quickly completed freezing. Excessive time in the blast freezer dries the dough surface, which causes bread faults. In the example given in Fig 10 the optimum freezing time was between 50 and 55 min.

Fig 10 Series of photos showing cut cross sections of dough sampled during the freezing process. This illustrates the soft core which eventually freezes solid.

A trial was conducted to compare freezing rate (Appendix 2). Dough was mixed to a finished dough temperature of 17°C and scaled to 550g dough pieces which were frozen at -35 and -20°C in blast freezer and -20°C in a chest freezer. The doughs took 45min to reach a core temperature of -5°C when frozen at -35°C and 120min in the chest freezer. Freezing rate did not appear to influence frozen shelf life. The literature has recommendations for fast and slow freezing rates (Brummer, 1995). For commercial production it is more energy and time efficient to use a blast freezer. The
most important factor is to minimise the dwell time as excessive surface drying reduces baking quality.

3.6 Frozen Storage

3.6.1 Storage Freezers
Domestic storage freezers with a 700 litre capacity were modified to improve the thermostatic control and to allow us to work with frozen storage temperatures between 0 and -30°C. Modification to the thermostat was achieved by fitting a standard PID (Proportional, Integral and Derivative) controller with an auto-tuning function (see appendix 3 for further details). The freezers were also set up with thermocouples to allow constant temperature recording.

3.6.2 Storage trial
A trial was conducted to compare frozen storage temperature (Appendix 2 for further detail). Dough pieces were stored at –10, -20 and -30°C. All doughs showed a decline in loaf volume with length of frozen storage, there was little difference between the treatments (Fig 11). However it was not viable to store dough at –10°C as the dough was not hard and produced off odours indicating that there was microbial spoilage.

The lack of difference between the storage temperatures was not expected. Cauvain (1996) found shorter proof times for doughs stored at -20°C, however they found that loaf volumes were lower for the doughs stored at –20°C compared to those at -10°C.

Most commercial freezers operate at –18 to -20°C, this appears to be an appropriate storage temperature. Frozen doughs should be packaged to reduce moisture loss. Loss of moisture during storage or drying is a major cause of poor shelf life which is avoidable with correct packaging.

Changes occurring in the dough during frozen storage were a major focus of this study and are reported under the microscopy and dough rheology sections.
3.7 Thawing, Proofing and Baking

Slow thawing of dough pieces is consistently recommended in the literature. For this study a 16 hour thaw at 0°C was used for the 550g dough pieces. This slow thaw allows the dough to completely thaw before yeast fermentation begins to proof the dough. Dough pieces were then proved at 25°C for 70min and then at 35°C for 60min. A fixed proof time was used for all testing in this study. Another method is to prove to a fixed height and allow a variable proof time. It was clearly indicated that industry was seeking to use fixed proof times for its clients if possible. Having now completed the study we recommend that by adjusting proof time to allow for the loss of yeast activity that some recovery of loaf volume can be achieved. This would then form a means of extending shelf life for perhaps up to a month.

Baking was consistent with the production of fresh bread.
3.8 Bread Faults

Most of the report uses loaf volume as an objective measure of storage performance. It is a measure of gas production and retention. Scoring of the bread indicated that there were other faults associated with the bread which tended to increase with frozen storage. Large blisters occurred under the top crust (Fig 12). This can be the result of several factors including: break down of internal cell structure with coalescence of cells to form large holes due to weakening of the cell structure/gluten network; or excessive drying of the surface which makes it more rigid during the proof and baking. To reduce this fault we recommend minimising the time the dough spends in the blast freezer and ensuring that the dough is packaged with an effective barrier for storage.

Small white spots or blisters were very common and tended to increase in all treatments with extended storage. These blisters can also be seen on fresh dough made from very weak flour or where fat levels are low. The blisters are caused by a weakened gluten structure where the gas expands and escapes from the surface of the dough rather than being held in the dough. This weakening on the surface is exacerbated by drying of the dough surface either during initial freezing or frozen storage. This fault is very difficult to avoid with extended storage.
3.9 Rapid storage test

A major objective of this study was to reduce the time taken to complete storage trials, which can take from between 3 to 6 months.

Moisture migration and growth of ice crystals appear to be the major changes which occur during storage and contribute to loss of shelf life. When moisture migrates from the surface it can result in drying and internally it can result in dehydration of protein. Ice crystal growth disrupts the gluten structure and ruptures yeast cells. Rates of moisture migration and ice crystal growth are increased when the temperature of the dough is cycled. This is one of the reasons that constant storage temperature is considered very important to optimise frozen storage life.

A range of trials were conducted to determine the effect of temperature cycling on yeast activity measured using the fermentagraph and baked product quality. These results were compared to the changes observed using long term storage at a constant temperature of -20°C (Figs 13 and 14).

Fig 13 Three doughs tested for loaf volume Over an extended period of frozen storage

Fig 14 Three doughs tested for gassing power using the fermentagraph
Frozen dough production

The results for each dough were expressed on the basis of a percentage change to allow direct comparison of the loaf volume and fermentagraph results (Figs 15 to 17). For dough one the fermentagraph showed a greater rate of decline than did loaf volume, this result is hard to explain as the loss of gassing power would be expected to have an equal impact on loaf volume with other losses perhaps contributing to a higher rate of decline. This would be expected to be due to gas escape in addition to the loss of gassing power. For dough two, the rate of change was quite parallel and as for dough one, the loss of gassing power was consistently higher than the loss of loaf volume. For dough three, the loss of gassing power showed a greater rate of decline than loaf volume. Note the rate of change is measured against the first or initial loaf volume or fermentagraph in this case at 2 weeks. Another way to have assessed this may be to complete the comparison against a fresh dough.

Fig 15 Comparing % change in loaf volume and fermentagraph during frozen storage (dough 1).

Fig 16 Comparing % change in loaf volume and fermentagraph during frozen storage (dough 2).

Fig 17 Comparing % change in loaf volume and fermentagraph during frozen storage (dough 2).

A series of trials were conducted with temperature cycling at a range of temperatures and times. Temperatures above -10°C were found to be difficult to work with as the dough became soft and easily damaged. It is clear that in frozen transport and storage
Frozen dough production

these temperatures would be a disaster for dough pieces that are stacked on top of each other or in contact with other pieces.

The results of an initial cycling treatment are presented in figs 18 to 20 where we were looking to simulate the change in loaf volume and fermentagraph results shown by the long term storage samples. The effect of cycling was clearly to reduce gassing power and loaf volume. In this test a cycle of 8 hours at -5°C was used with doughs returned to -20°C for 24 hours before another -5°C cycle. At -5°C the doughs were soft and required special handling to avoid physical damage. This would be considered to be a real problem in commercial storage or transport where any contact with other dough pieces or stacked dough would result in complete spoilage. Note for these trials the first cycle result is a constant storage dough with no cycling, this was used to calculate the percentage change.

Under these cycling temperatures the rates of change in gassing power and loaf volume resembled the pattern for dough 3 in constant storage. The patterns and rates of change were similar for all three doughs. These results were not considered acceptable where the rate of change was not high enough and the patterns were not correct.

Fig 18 Baking test for cycling between storage at -20°C and -5°C for 8 hours.
Fig 19 Fermentagraph results for doughs cycled between storage at -20°C and -5°C for 8 hours.
Fig 20 The rate of change in loaf volume and fermentagraph for doughs cycle between constant storage at -20°C and -5°C for 8 hours.
Increasing the duration of storage at -5°C to 15 hours appeared to improve the relationship, however the dough pieces were soft and difficult to work with (Fig 21).

![Dough 1 15 hrs -5C](image)

*Fig 21 Loaf volume and fermentagaph results for dough 1 cycled through 15 hours at -5°C before being returned to storage at -20°C for at least 24 hours before another -5°C cycle.*

In addition to placing the dough pieces in storage freezers at different temperatures we also trialed the use of a microwave oven with the aim of achieving a more consistent change in temperature throughout the dough. The rates of change were low for this treatment and the pattern was not consistent with the long term storage (Figs 22 and 23). Although we did not continue with this approach we were surprised by its potential. However there were too many unknowns being introduced such as – what is the effect of microwaves on yeast viability?

![Dough 1 microwave](image)

*Fig 22 The effect of cycling between constant storage at -20°C and a microwave oven on low for 40 sec on loaf volume.*

![Dough 1 microwave](image)

*Fig 23 Rates of change for loaf volume and fermentagaph for doughs cycled between -20°C storage and a microwave for 40 sec on low.*
Frozen dough production

Subsequent trials used cycling between -10°C and -20°C. Times at the higher temperature ranged from 8 to 60 hours. The cycle that gave the best results consisted of the following.

The dough was stored for a minimum of 48 hours after initial freezing. It is then cycled through the following.

Sixteen hours at -10°C and returned to -20°C for 8 hours followed by 16 hours at -10°C and then returned to -20°C for a minimum of 24 hours before either another cycle commences or it is thawed for bake-off. In this cycle the dough takes four hours to reach equilibrium when moved to -10°C and two hours to recover when returned to -20°C.

The pattern of change in fermentagraph and loaf volume was quite similar to the original constant storage trial for doughs one and two (Fig 24 and 25). We were not able to complete the work for dough three as we were using a commercial concentrate which was no longer available. From the cycling results we estimate that each cycle was equivalent to one month’s frozen storage. We consider this an appropriate method for the rapid evaluation of frozen storage life for bread doughs.

This work also emphasises the impact of temperature cycling during storage and transport. It is extremely important to avoid this as it is probably the largest threat to quality experienced in frozen dough processing.

Fig 24 Percentage change on loaf volume and fermentagraph for dough one using cycling to -10°C for 2 16 hour periods per cycle

Fig 25 Percentage change on loaf volume and fermentagraph for dough two using cycling to -10°C for 2 16 hour periods per cycle
3.10 Microscopy

Electron microscopy was used to study the changes occurring in the frozen dough structure. Details of this work are described in Appendix 4. Further work is being prepared for publication in a PhD thesis.

Immediately after mixing the dough presents as a continuous gluten structure which forms around the starch granules and gas cells appearing as voids (Plate 1). After freezing the presence of ice crystals are observed as small irregular shapes throughout the dough structure (Plate 2). With extended storage the ice crystals increase in size and appear to disrupt the gluten structure (Plate 3). The growth of the ice crystals has been followed through frozen storage from one day to 14 weeks. Cycling the dough between –10 and -20°C for periods of 66 hours twelve times resulted in an appearance of similar ice crystal disruption and growth. This indicates that cycling -10 and -20°C can result in similar changes to continuous frozen storage.

Plate1 Scanning electron micrograph of a frozen fracture surface of dough sampled immediately at completion of mixing. Micrograph shows a dense structure with few spherical voids. Starch granules are firmly embedded in the gluten matrix.
Plate 2  Scanning electron micrograph of a frozen fracture surface of dough stored for 1 day @ -20°C. Porous structure with uniform size voids. Continuous gluten network. Starch granules are firmly attached to gluten strands.

Plate 3  Scanning electron micrograph of a frozen fracture surface of dough stored for 14 weeks @ -20°C. Size of angular dark voids has increased when compared to dough stored for 1 day (plate 3).
3.11 Dough Rheology

In an attempt to measure the changes in gluten strength occurring during frozen storage a dough rheology test was developed. A feature of the test was that the dough would be continuing fermentation during the test.

Two test methods were evaluated for the measurement of dough strength during frozen storage. This work is explained in more detail in appendix 5. Doughs were modified with gluten, ascorbic acid, cysteine and fat to give predictable changes in rheology. The modified extensograph test was selected over the parallel plate test as providing a more effective measure of dough strength.

The modified extensograph test was used to compare dough stored at constant temperature (-10 and -20°C) and with temperature cycling (Fig 26). There was almost no change in dough strength for the non-yeasted dough over the storage period. This indicates that ice crystal growth is not weakening the dough structure. However it should be noted that in this procedure the dough is remoulded and rested which could allow some repair of any damage due to ice crystal damage, however the damage would still be considered minimal if a simple remoulding effectively recovers the original dough strength.
Fig 26 Modified extensograph test to measure dough strength for non-yeasted and yeasted doughs under different frozen storage conditions.

The fermented dough showed an increase in dough strength in storage up to 56 days and after this the strength was constant. The -20°C constant storage had a consistently lower strength although the pattern of increase in strength was similar to the other storage treatments. The increase in dough strength with fermentation appears to be consistent with that of Hoseney who attributed this to the production of hydrogen peroxide as a product of yeast fermentation.

This work was completed in triplicate and the increase in dough strength is statistically significant. The result suggests that the formation of ice or the release of glutathione do not break down the gluten structure. However it does not preclude the possibility that the ice may contribute to cell rupturing and increased loss of gas during proving and baking.

3.11 Protein testing

The following methods have been applied to the measurement of protein to determine the effect of frozen storage on this component.

- Capillary electrophoresis
- HPLC
- Field Flow Fractionation

At the time of preparing this report the work was still in progress and will be reported in detail in a later report.
Appendix 1

Mixing for optimal frozen dough production.

1. Objectives

To determine the effects of dough temperature on mixing requirements.

To determine the mixing requirements for optimal frozen dough production.

To assess the use of ice addition for dough temperature control

2. Background

Fermentation periods before freezing have been shown to reduce the shelf-life of frozen doughs for bread production (Merritt, 1960). It appears that once yeast is activated it is more susceptible to damage by freezing. Yeast activity can be minimised by reducing finished dough temperature and processing time prior to dough freezing. Rapid dough processes have been selected to reduce processing times. Using rapid dough systems, most literature recommends the use of low finished dough temperatures (below 20°C) to achieve optimum frozen dough shelf-life.

A feature of rapid dough systems is that they require that the dough is fully developed in the mixer. However there is little information available on the development of dough at low temperatures. We hypothesize that at lower temperatures the mixing requirement is greater to achieve the chemical reactions required for dough development. We also predict that mixing is critical for frozen doughs where the gluten structure is weakened by frozen storage. Optimum mixing is recognised to result in a more tolerant dough structure, which would be expected to enhance frozen dough performance.

The present study seeks to establish the effects of dough temperature on mixing and control of dough temperature using ice addition.
Appendix 1 Dough Mixing

3. Methods

Two mixers were used for this study to provide different mixing actions and intensities, and different heat transfer conditions.

1. The Morton mixer is a Z arm mixer with an intensive action. This instrument incorporates a water jacket and provides good control over water temperatures. A flour weight of 1.2 kg was used with this mixer as it provides the most reproducible mixing curves.

2. An Eberhardt mixer was fitted with a water jacket. The jacket was specifically designed by BRI for this medium intensity spiral mixer. The water jacket provides excellent control over dough temperature and the design concept is recommended for test bakery systems using spiral mixers. A flour weight of 3kg was used for mixing doughs on the Eberhardt mixer.

Mixer temperature was controlled by pumping water at a constant rate through the jackets on both the Morton and Eberhardt mixers. Water jacket temperatures of: 0, 8, 16, 24, 32 and 40°C were used to change dough temperature conditions.

Mixing curves

All mixing curves were obtained with the BRI, Easymix system (Zounis and Quial 1997).

Temperature data

Temperature curves were collected at 15 sec intervals using a Cyclops, compac 3 infrared thermometer. The cyclops was placed above each mixer and directed at a location in the mixer, which allows constant dough contact. The infrared instrument was compared to thermocouples placed in the mixer and checked with thermometers in the dough. It was found to provide a very effective means of collecting dough temperature data. This was the first time that this system had been successfully used.

Formulation

A bread making formulation was used to represent general commercial production

<table>
<thead>
<tr>
<th>%</th>
<th>Temperature</th>
<th>Commercial 12% protein</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flour</td>
<td>100</td>
<td>-10°C</td>
</tr>
<tr>
<td>Salt</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Improver</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Fat</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Yeast</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>58</td>
<td>4°C</td>
</tr>
</tbody>
</table>
Appendix 1 Dough Mixing

Statistics

All testing was repeated 3 times and unless specified the results shown are the mean of the three tests. The error bars shown on the graphs are the mean standard deviation.

4. Results

The relationships between jacket temperature and mixing parameters were linear and very close. As jacket temperature increased the time to peak development (TTP) decreased with $R^2$ values close to one (Figures 1 and 2). Standard deviations for the test also decreased with dough temperature. At low temperatures the mixing curves had less pronounced peaks and the TTP was more difficult to measure. Standard deviations ranged from 1.9 to 6.8% for the Morton and 0.7 to 7% for the Eberhardt mixer. The relationships of TTP with the dough temperature was very similar to those expressed on the basis of Jacket temperature (Figures 3 and 4).

![Figure 1 Morton mixer, jacket temperature versus TTP.](image1)

![Figure 2 Eberhardt mixer, jacket temperature versus TTP](image2)
Appendix 1 Dough Mixing

**Figure 3** Morton mixer, dough temperature at TTP versus TTP

**Figure 4** Eberhardt mixer, dough temperature at TTP versus TTP.

Morton mixing times to peak ranged from 3 to 6 min and the Eberhardt from 8 to 15 min this reflects the higher intensity of the Morton mixer. Despite the different intensities the trends were very similar for each mixer. The implication of this work is that to prepare doughs with finished dough temperatures below 20°C it takes considerable longer to mix these doughs whether on a high or low intensity mixer.
Appendix 1 Dough Mixing

**Dough temperature**

Dough temperatures were collected at 15 sec intervals. For both mixers at each jacket temperature the doughs showed a linear increase in temperature (Figures 5 and 6). The rate of temperature change increased with increasing jacket temperature. The rate of temperature increase was higher for the Morton mixer and this would be expected with the higher rate of energy input. Dough temperature results were highly reproducible and the 3 repeats for the Morton zero jacket temperature are shown as an example (Figure 7).

![Figure 5 Morton mixer dough average temperature data for each water jacket temperature.](image)

![Figure 6 Eberhardt mixer dough average temperature data for each water jacket temperature.](image)
Appendix 1 Dough Mixing

Figure 7 Morton mixer showing data from 3 repeats of dough temperature data.

Work input

Work input showed a similar response to dough temperature to that shown by the TTP. For both mixers the total work input required to achieve peak dough development decreased as the jacket temperature increased (Figs 8 and 9). This is consistent with the decrease in both mixing time and dough consistency.

Error! Not a valid link.

Figure 8 Morton mixer total work input to peak development versus jacket temperature.

Error! Not a valid link.

Figure 9 Eberhardt mixer total work input versus water jacket temperature.

Work input was also calculated on a Whr/kg basis to allow some comparison between the mixers (Figure 10). The more intense action of the Morton mixer puts more work into the dough for a given rise in dough temperature. This would be both due to the higher rate of energy input and the more enclosed nature of the Morton mixer which does not allow as much temperature loss. What is also interesting from this data is the similarity of dough temperatures at TTP, for jacket temperatures above 16 C.

Error! Not a valid link.

Figure 10 Work input expressed as Whr/kg for the Morton and Eberhardt mixers, versus dough temperature at the time to peak.
Appendix 1 Dough Mixing

Dough consistency

The height of the mixing curves provides a measure of dough consistency. This has been shown to be sensitive to water addition with increasing water reducing the peak resistance. As dough temperature increased the peak resistance showed a linear decrease for each mixer (Figures 11 and 12). The high peak resistance at low finished dough temperatures is consistent with stiff doughs that are difficult to machine.

Error! Not a valid link.

Figure 11 Morton mixer, peak resistance versus dough temperature at TTP

Error! Not a valid link.

Figure 12 Eberhardt mixer, peak resistance versus dough temperature at TTP.

Ice Addition

Replacement of dough water with ice is a common approach to the reduction of finished dough temperature. Ice addition is used in both hot climates to achieve target dough temperatures for fresh bread production and is also used to achieve dough temperature under 20°C for frozen dough production. Crushed ice was added to the dough mixing stage at the following levels; 0, 20, 40 and 60%. These high levels reflected those observed in industry.

When ice was added the mixing time increased (Fig 13). The increase was more than could be accounted for by the reduction in dough temperature and there was a delay in dough development until the ice effectively melted. This meant that the initial energy input during mixing was melting the ice rather than developing the dough (Figs 14 and 15).
Fig 13 Average dough temperature monitored during mixing with four levels of ice addition to replace the dough water, for the Morton mixer.

Fig 14 Effect of increasing ice addition on TTP, using the Morton mixer.
Appendix 1 Dough Mixing

Fig 15 Effect of increasing ice addition on Work input, using the Morton mixer.
APPENDIX 2

EFFECT OF FREEZING RATE AND STORAGE TEMPERATURE ON FROZEN DOUGH STABILITY

S. Zounis$^1$ and K.J. Quail$^{1,2}$

$^1$Quality Wheat CRC Limited, Locked Bag No. 1345, North Ryde, NSW 2113, Australia
$^2$BRI Australia Limited, PO Box 7, North Ryde, NSW 2113, Australia

The frozen dough industry is rapidly expanding (El-Hady et al. 1996; Berglund et al. 1991; Dubois & Blockcolsky 1986). However, frozen dough deteriorates during storage (Inoue et al. 1994). As the storage period increases, the time to proof to a given height increases, the loaf volume decreases and the loaf has a poor appearance (Dubois & Blockcolsky 1986).

The loss of quality of bread baked from frozen dough is mainly attributed to yeast cells which die during storage. Less gassing power is provided by the yeast, which is required for dough leavening. Reducing substances, such as glutathione, are leached from dead yeast cells which weaken the gluten structure. Structural damage to the gluten network and to yeast cells is also caused by ice crystals (Inoue et al. 1994; Räsänen et al. 1995).

Stability during storage is affected by a number of factors such as: formulae, initial freezing rate, and storage conditions. Commercial doughs are not always maintained at a constant temperature. Partial thawing may occur during distribution and storage. It is known that fluctuating temperatures promote recrystallization processes. This affects the texture and quality of frozen foods.

A baking trial was conducted to investigate frozen storage above and below the commercial storage temperature (around -20°C). Doughs, prepared with two formulae, and frozen at three different freezing rates, were stored at -10°C, -20°C and -30°C. Doughs were thawed and baked after storage periods between one day and 16 weeks.

MATERIALS AND METHODS

A commercial bakers flour with a protein content of 12.8% (N x 5.7) and a farinograph water absorption of 64.5% was used throughout. The bread formula (flour basis) consisted of flour (100), salt (2.0), fat (2.0), improver (100 ppm ascorbic acid) (1.0), compressed yeast (5.0) and water (55.0).

Bread doughs (4 kg flour) were mixed in a modified Eberhardt mixer to 10% past peak development. The final dough temperature was maintained at 17°C by chilling the flour and water ingredients, and circulating water at 0°C through the jacketed mixing bowl. Dough was scaled into 550g pieces, rounded after five minutes rest, then moulded and frozen ten minutes after mixing. Doughs pieces were frozen either in a blast freezer at -35°C or -20°C or in a chest freezer at -20°C (no air blast). All Doughs were frozen to a core temperature of -10°C. After freezing doughs were placed in double plastic bags (HDPE) and transferred to a storage freezer maintained at -10, -20 or -30°C. Doughs were thawed and baked after storage for 1 day, 1 week, 2 weeks, 4 weeks, 8 weeks and 16 weeks. Doughs were thawed for 16 hours in a retarder at 0°C, then panned and transferred to a proving cabinet at 25°C and 85% relative humidity for one hour and fifteen minutes. Following this, doughs were proved at 35°C and 85% relative humidity for one hour and baked in a Rotel modular oven at 240°C for 25 min.
The height of the dough was measured just before entering the oven. The loaf volume was measured after baking when loaves were cool. The loaf score was measured the next day. Each freeze-rate/storage-temperature treatment was in triplicate, each mix separated by a week.

RESULTS AND DISCUSSION
The height of dough after proving was highly correlated to the loaf volume for all freeze rate and storage temperature treatments (mean $R^2 = 0.92$, standard deviation = 0.06). The height of the dough after proving was considered as a combined measure of the yeast gassing power and the ability of the dough to hold gas. These results show that the measurement of the height of the proved dough did not provide additional information than did the loaf volume.

The loaf volume decreased with time in frozen storage for all freeze rate and storage temperature treatments as expected. The freezing rate had no effect on loaf volumes. Doughs stored at -10°C had higher loaf volumes than those stored at -20°C or -30°C. Figure 1 shows the effect of frozen storage temperature on the loaf volume of bread baked from doughs frozen at the commercial rate (blast frozen at -35°C) and stored for periods up to 16 weeks. Storage at -10°C resulted in higher loaf volumes up to about 80 days. However, it is not practical to store doughs at -10°C, since the doughs were not hard at this temperature and were susceptible to damage from handling and stacking.

![Graph showing loaf volume vs. days in frozen storage for different temperatures]

Figure 1 Effect of frozen storage temperature on the loaf volume of bread baked from doughs frozen at -35°C in a blast freezer and stored for periods up to 16 weeks

In this trial loaf volume did not reflect loaf quality. The doughs slowly frozen in the chest freezer and stored at -10°C, had developed a discoloured speckled surface. The baked loaves had a mottled surface colour and poor crumb structure. The crumb colour, however, was not different to the other treatments, but the loaf did have an off or rancid odour and taste.
A high fat and high sugar formulation dough did not show improved stability as expected from a richer formula (results not shown). Discolouration of doughs stored at -10°C, was more pronounced than the leaner formula.

CONCLUSIONS AND FURTHER WORK
This paper presents the results of an initial baking trial investigating the effect of storage temperature on loaf volume. These results show that there was tolerance to variation in freezing rates in the blast freezer. A faster freezing rate, however, allows a shorter freezing time which is more suitable for production. There was also tolerance to storage at temperatures at or below -20°C. These results did not measure tolerance to fluctuations in storage temperatures. In further work, the effect of partial thaw-freeze cycles and formulae on storage stability will be investigated.

These results emphasise the complexity of running baking trials. Results are difficult to interpret, thus, there is a need to develop tests which are more specific. Focus will be placed on developing methods to measure damage to the dough structure caused by ice crystals and water migration. Conformational changes occurring to the dough structure will also be studied.

ACKNOWLEDGMENTS
The authors wish to thank Richard Harris for his technical assistance in mixing and processing doughs.

REFERENCES

Dubois, Donald K.; Blockcolsky, Doris Frozen bread dough, effect of additives, American Institute of Baking, Research Department, Technical Bulletin, 8(4), 1986.


Appendix 3 Control of Storage Freezers

Background
For the average domestic freezer the type of thermostatic control used is unsatisfactory for scientific purposes. It was found that the dead band of +/- 3 °C was unacceptable for the application. This meant that for a required temperature of –20°C the thermostat would fluctuate between –17°C and –23°C. It was desired that the dead band be less than +/-1°C. It was also desired that a display be available to visually monitor the temperature.

Description of installation
A standard off the shelf PID (Proportional, Integral and Derivative) controller was used with an auto-tuning function. A timer was also placed in the circuit to eliminate fast cycling of the refrigeration compressor, which may have resulted in the compressor burning out. In order to changeover the control from the freezer thermostat to the PID controller it was necessary to bypass the thermostat. This was done by disconnecting the main power supply from the inlet of the thermostat and the supply power to the freezer compressor. These two wires were joined so that the compressor ran permanently. The main power for the freezer was then plugged into the PID/timer circuit. For the PID to control the temperature of the freezer we needed to be able to measure the temperature of the freezer and input it to the PID controller. A Type K thermocouple was used and ran from the freezer chamber to the PID controller. The PID controller then controlled the temperature at the selected temperature set-point and displayed both the set-point and actual temperature in the freezer.
APPENDIX 4

SCANNING ELECTRON MICROSCOPY STUDY ON FROZEN DOUGH STABILITY

S. Zounis¹, K.J. Quail¹,² and M. Wootton³

¹Quality Wheat CRC Limited, Locked Bag No. 1345, North Ryde, NSW 2113, Australia
²BRI Australia Limited, PO Box 7, North Ryde, NSW 2113, Australia
³Department of Food Science and Technology, University of New South Wales, Kensington, NSW, 2052, Australia

INTRODUCTION
Frozen doughs are increasingly being produced by the baking industry. A shelf life greater than 3 months is necessary to make an Australia frozen dough industry viable. This is driven by the need for export opportunities for frozen dough products.

The shelf life of frozen bread dough is limited by yeast cells, which die in frozen storage. Reducing substances leached by dead yeast cells weaken the dough structure (Inoue et al. 1994). Yeast cells are more susceptible to freeze damage when activated in dough prior to freezing (Hino et al. 1987). The formation and growth of ice-crystals also damage the gluten structure (Räsänen et al. 1995). Deterioration is promoted by partial thaw-freeze cycles, which occurs during distribution and storage.

The aim of this work was to study the effect of frozen storage conditions on the microstructure of frozen dough using low temperature-scanning electron microscopy (LT-SEM).

MATERIALS AND METHODS
Frozen doughs were prepared with a commercial bakers’ flour (Goodman Fielder Mills, Australia) with protein content of 12.0% (N x 5.7). Lean formula bread doughs were mixed to 10% past peak development in an Eberhardt spiral mixer with 17°C final dough temperatures. Dough was divided into 550g pieces and blast frozen at -35°C 10min after mixing. After 50min blast freezing, dough pieces were bagged, then transferred to storage freezers at either -20±0.5°C or -10±0.5°C. Dough pieces were also stored at -20°C and subjected to partial thawing by holding at -10°C for 66 hours each week.

Dough fracture surfaces were examined by LT-SEM (Berglund et al. 1991), using a Cambridge Stereoscan S360 Scanning Electron Microscope with cold stage and cryo-chamber. The stage was cooled to -185°C with liquid nitrogen. Dough was kept frozen with liquid nitrogen at all stages from storage freezer to sample preparation and transfer into SEM. Doughs were examined 3sec and 10min after mixing and after 1 day and 10 weeks in frozen storage.

RESULTS AND DISCUSSION
Dough with 17°C final dough temperatures used in frozen bread dough production and 30°C doughs had identical microstructures when examined immediately after mixing. Figure 1 shows the microstructure of dough examined 3 seconds after mixing. It has a dense structure with starch granules firmly embedded in a well-developed gluten matrix.

Ten minutes after mixing the structure of the 17°C dough (Fig. 2) is similar to the dough structure examined 3sec after mixing (Fig. 1). No or little yeast activity occurs in 17°C
doughs in contrast to 30°C final dough temperatures used for fresh bread production. The structure of 30°C dough examined 10min after mixing (Fig. 3) was similar to the 17°C dough (Fig. 2) except for the large gas voids in the warmer dough caused by yeast fermentation.

After freezing and storage for 1 day at -20°C, ice-crystals formed in the dough represented by an even distribution of uniform sized angular voids in the microstructure (Fig. 4). Figure 5 shows the structure of lean formula bread dough with no added yeast and stored for 1 day at -20°C. It is similar to dough with yeast (Fig. 4) which confirms that voids were formed by ice-crystals and not formed by minor yeast activity. This also demonstrates the difficulty of distinguishing between yeast cells and starch granules using SEM, both micrographs contain 10μm diameter spheres, which may be either yeast cells or starch B-granules. It was therefore not possible to assess changes in yeast numbers with this technique.

After 10 weeks in storage at -20°C the structure has become more disrupted and ice-crystals have increased in size (Fig. 6). When stored for 10 weeks at -20°C and subjected to 8 partial thaw-freeze cycles, further disruption to the structure has occurred with starch granules detached from the matrix (Fig. 7). This may be caused by the higher water activity when subjected to -10°C cycles and ice-recrystallisation which is promoted by fluctuating temperatures known to occur in frozen food products (Reid 1990). When stored at -10°C for 10 weeks even larger voids are present (Fig. 8). This temperature is just below the freezing point of dough (-6° to -8°C) and hence water movement and yeast activity are more likely at this temperature.

CONCLUSIONS
The microstructure of lean bread dough stored under various sub-zero conditions was examined by LT-SEM. The microstructure of dough was altered during frozen storage. Fluctuating temperatures promoted this. Changes in dough microstructure caused by ice recrystallization are likely to impact on bread quality. These results support the common practice of mixing with lower final dough temperature to minimise yeast activity and storing at stable lower temperatures (-20°C) to maximise shelf life.

REFERENCES

ACKNOWLEDGEMENTS
Quality Wheat CRC Limited funded this work. The authors wish to thank BRI Australia Limited for its support throughout this project and extend their gratitude to Dr Melvyn Dickson and staff of the University of New South Wales Electron Microscope Unit for the use of equipment and assistance.
APPENDIX 5

EVALUATION OF PHYSICAL DOUGH TESTS FOR ASSESSMENT OF FROZEN DOUGH STABILITY

S. Zounis¹, K.J. Quail¹,² and M. Wootton³

¹Quality Wheat CRC Limited, Locked Bag No. 1345, North Ryde, NSW 2113, Australia
²BRI Australia Limited, PO Box 7, North Ryde, NSW 2113, Australia
³Department of Food Science and Technology, University of New South Wales, Kensington, NSW, 2052, Australia

Frozen doughs are increasingly being produced by the baking industry (Autio and Sinda, 1992; El-Hady et al., 1996). The shelf life of frozen dough for bread production is limited by deterioration of the dough structure during storage (Berglund et al., 1991). Weakening of the dough structure is caused by (a) reducing substances released from dead yeast cells and (b) the formation and growth of ice-crystals (Inoue et al., 1994; Räsänen et al., 1997). Deterioration is promoted by partial thaw-freeze cycles, which occurs during distribution and storage (Inoue et al., 1994; Berglund et al., 1991). A shelf life greater than three months is necessary to make an Australian frozen dough industry viable. This is driven by the need for export opportunities for frozen dough products.

Methods are required to measure changes to the structure of dough during frozen storage. The rheological behaviour of dough is important for the successful manufacturing of bakery products (Menjivar, 1990). The lack of understanding about dough rheology is further complicated by yeast, a live biological system that is constantly altering the properties of the dough as well as its shape. There is an immediate need for a test to measure physical changes to thawed frozen bread dough containing yeast.

The aim of this study was to evaluate an extensograph and compression test and to determine which method was the most suitable for measuring differences in the rheological properties of thawed and fermented dough after various periods of frozen storage and various frozen storage treatments.

MATERIALS AND METHODS

Frozen doughs (100% bakers’ flour, 2% shortening, 1% improver [100ppm ascorbic acid], 55% water) were prepared with 0, 15, 30, 45 and 60ppm L-Cysteine-HCl. Cysteine is a reducing agent and when added to dough, will reduce its strength and increase its extensibility. Hence, the behaviour of dough containing cysteine is predictable in physical tests. The addition of cysteine to doughs in the present experiment will produce doughs, which mimic the effects of (a) glutathione (a reducing agent released from dead yeast cells), or (b) the weakening effect caused by frozen storage. All doughs were prepared with 0% and 4% compressed yeast.

Doughs were mixed in an Eberhardt mixer to peak development for each cysteine level and to a final dough temperature of 15°C. Doughs were divided into 100g pieces, rounded, blast frozen at –35°C for 15min, bagged and stored at –20°C. Dough test pieces were taken from the same mix for both the compression and extensograph tests. Each dough piece was equilibrated to –20°C and thawed in refrigerated incubators at 23°C for 4 hours before testing in a random order.
Compression test:
A uniaxial compression test between lubricated parallel plates was chosen since it may be used with doughs containing yeast and it is possible to obtain fundamental units. After thawing, the dough pieces were rounded and rested for a further 1 hour at 23°C before testing. The dough pieces were compressed between polytetrafluoroethylene plates fitted to TA-XT2i texture analyser. Dough pieces were compressed until 50% strain and held there for 60s to record a stress relaxation curve (Cullen-Refai et al., 1988). The maximum force or peak ($F_p$), the final force after the 60s rest ($F_f$) and the difference between the peak and final force ($F_{p-f}$) were recorded.

Extensograph test:
The Brabender extensograph was chosen, since (a) it is used extensively as an industry standard test for flour, and (b) no modification to the instrument is required for use with thawed frozen dough. The objective was to find a test method without modification to the instrument that would work on all types of dough. Hence, a rest time of one hour was necessary after moulding, since a shorter rest period would increase the likelihood of doughs containing no yeast and no cysteine of going off the extensograph scale. After thawing, the dough pieces were rounded followed by moulding and rested for 1 hour at 23°C before testing.

Both tests were repeated with a 20min-rest period after moulding to determine the effect of rest time after moulding on the coefficient of variation ($cv$). All tests were assessed for reproducibility and the ability to discriminate between the different cysteine levels. The optimum test was used to assess the changes in the physical properties of doughs containing 0 or 4% yeast and no cysteine in a frozen storage trial where doughs were stored for 14 weeks at (a) -20°C, (b) –20°C with 14 partial thaw freeze cycles (each cycle at –10°C for 66 hours), and (c) -10°C.

RESULTS AND DISCUSSION
The peak force ($F_p$), final force ($F_f$) and peak-final force ($F_{p-f}$) decreased with increasing cysteine levels in both the 20min and 60min compression tests for doughs with or without yeast. The $F_f$ showed the greatest discrimination (highest $R^2$ values) between the cysteine levels for doughs with and without yeast in both the 20min and 60min tests. A plot of the $F_f$ against cysteine level for the 60min test is shown in figure 1. The lines of best fit have similar slopes between the yeast and non-yeast doughs. The lower slope for the no-yeast compared to the 4% yeast dough in the plot of the $F_{p-f}$ against cysteine level (figure 2) suggests that yeast added to the dough weakens the dough structure, since the dough relaxes to a greater extent when held at a constant strain. This is probably due to the open cell structure that is formed.

The $R_{max}$ decreased and extensibility increased with increasing cysteine level for both yeast and non-yeast doughs in the 60min extensograph test (figures 3 and 4). This trend was expected, similarly in the 20min test, however, the slopes were lower.

The coefficient of variation ($cv$) for each parameter measured in all tests was greater in doughs with yeast than without (table 1). The mean $cv$ from all 5 parameters in the 60min test was 5.6 and 8.4 for non-yeast and 4% yeast doughs respectively. These results confirm that tests performed on doughs containing yeast give more variation. The $cv$ was generally less for the extensograph than for the compression parameters in both the 20min and 60min tests for doughs with yeast. For non-yeast doughs, the $cv$'s were similar for all parameters in
the 60min tests, but the compression test parameters had lower cv’s than the extensograph in the 20 min test. There was no apparent trend in the cv, for the individual parameters, against cysteine level in all tests.

Based on these results, the extensograph test with 60min rest after moulding was more useful than the other tests, having lower cv values (6.1 and 7.7 for R_max and extensibility)
respectively) for doughs with yeast, and high $R^2$ values (0.80 and 0.76 for $R_{\text{max}}$ and extensibility respectively) for doughs without yeast. This test was selected for applying to a storage trial.

**Storage trial**

Yeast addition to doughs gave lower $R_{\text{max}}$ and extensibility values, due to the aerated structure in doughs with yeast. Storage at $-20^\circ\text{C}$ had significantly lower $R_{\text{max}}$ (593) values in doughs containing yeast than when stored at either $-10^\circ\text{C}$ (658) or cycled (655) ($P<0.01$) (figure 5). This demonstrates dough properties are affected by storage conditions. It was expected that storage at $-10^\circ\text{C}$ or cycling would promote weakening of the dough structure and cause the $R_{\text{max}}$ to decrease rather than increase. The increase in the $R_{\text{max}}$ may be due to the stronger oxidative effects of yeast at the higher storage temperatures ($-10^\circ\text{C}$ and cycling to $-10^\circ\text{C}$). This is supported by the lower slope of the 4% yeast doughs compared to the no-yeast doughs in the plots of $R_{\text{max}}$ vs cysteine (figure 3). The oxidative effects of yeast ($\text{H}_2\text{O}_2$) may be counteracting the reducing effect of cysteine. In doughs with no yeast and under the same storage conditions, the results were inverted with doughs stored at $-10^\circ\text{C}$ having an $R_{\text{max}}$ significantly lower (900) than when stored at either $-20^\circ\text{C}$ (960) or cycled (965) ($P<0.05$). The higher temperature ($-10^\circ\text{C}$) may promote weakening of the structure more than cycling between the two temperatures. These results demonstrate the difficulty in interpreting data from physical tests with doughs containing yeast.

![Figure 5](image)

**Figure 5.** Extensograph test applied to a 14 week frozen storage trial. Error bars indicate LSD.

**CONCLUSIONS**

The results of either the compression or the extensograph tests are very promising, given the difficulties presented when testing doughs containing yeast. The results of the above experiments indicated the modified extensograph test with one-hour rest after moulding was suitable for using with thawed frozen dough containing yeast. When this test was applied to a frozen storage trial where doughs were stored under different conditions for 14 weeks, there
were significant differences between the $R_{\text{max}}$ of yeasted doughs stored at $-20^\circ\text{C}$ and doughs stored at $-20^\circ\text{C}$ with partial thaw-freeze cycles or $-10^\circ\text{C}$.

REFERENCES


ACKNOWLEDGMENTS

This work was funded by Quality Wheat CRC Limited, North Ryde, NSW. The use of facilities at BRI Australia Limited is gratefully acknowledged.