QUALITY WHEAT
CRC PROJECT REPORT

Program 3: Processing of Wheat and Wheat Products

Project 3.4.1

"Bubbles in Food"
Conference

9 - 11th June 1998
Manchester, UK

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Contents

1 Executive Summary

The Bubbles in Food International Conference was held at the University of Manchester, United Kingdom from 9th to 11th June 1998. The last conference hosted by the Satake Centre, held during 1996, focused on novel uses of cereals. It is the intention of the Conference organisers to try and organise similar conferences every two years. The next conference is planned for 2000 and will again focus on the novel uses of cereals. The Bubbles in Food Conference featured a wide variety of foods including bread, biscuits, beer, wine, extruded products, whipped creams and aerated desserts. Delegates came from over 15 different countries.

Conference Highlights

- The coupling of image analysis techniques with light microscopy, scanning electron microscopy and X-ray computerised tomography to study the bubble structure of bread doughs and crumb. The latter technique is especially suited to studying fragile fermenting doughs.
- Importance of establishing the correct pixel intensity threshold level for segmenting a bubble image into cell wall and gas bubble regions. Failure to adjust this threshold level to the brightness intensity of each image (eg using fixed level thresholds) can lead to erroneous results.
- The density of doughs following mixing can be explained as a balance between air entrainment and disentrainment. By studying the rates of these two parameters much can be learnt about the mixing process of different mixers, from which new improved mixer designs can potentially be developed.
- Final bubble structure depends upon Oswald ripening (growth of large bubbles at the expense of smaller ones), bubble coalescence, and uniform bubble growth during fermentation and baking. These three mechanisms are in turn influenced by the surface tension, surface dilational moduli, biaxial stress, strain hardening and fracture strain of the dough within which the gas bubbles grow, shrink and merge.
- Of all the dough parameters that influence bubble structure, the most important relate to the rheology of the dough. However, surface active proteins and lipids may also play an important role. To determine the role of rheology in the evolution of bubble structure requires that this data be gathered under equivalent biaxial stress conditions encountered in the dough.
- The growing information linking chemistry and rheology of bread dough to the bubble structure of dough will help in understanding formation and preservation of bubble structure during production in the bakery. Via improved specifications for flour production and better equipment and processing design, improvements can be made in bread quality with specific types of bubble structure being tailored for the end consumer.

Around April 1999 the American Association of Cereal Chemists will publish the fully edited Conference Proceedings.

2 Introduction

This report presents information relevant to bread research that was presented at the "Bubbles in Food" International Conference held in Manchester, United Kingdom on the 9th - 11th June 1998. The Conference was organised and hosted by the Satake Centre for Grain Process Engineering, Department of Chemical Engineering, University of Manchester Institute of Science and Technology (UMIST).

About 160 delegates from 15 different countries attended the conference with most of those attending from the Europe Union. Since bubbles play a major role in many different foods, any conference focusing on bubbles would be interdisciplinary. This was a promise the "Bubbles in Food" Conference lived up to, with chemists, physicists, biochemists, engineers, and theoreticians among the delegates. Similarly the topics were equally as diverse; including baked goods, beers, wine, extruded products, whipped creams and aerated desserts.

Two years ago the Satake Centre organised an international conference on the novel uses of cereals. It is their intention to have biennial conferences; the next will again focus on novel uses of cereals.

This report focuses on presentations that I found particularly relevant to bread baking research. These particular presentations are listed in the References section on page 15. Appendix I, page 16, gives a complete list of the presentations given at the Conference.

The Conference Proceedings are being edited by one of the Conference Organisers, Dr Grant Campbell, before their publication around April 1999 by the American Association of Cereal Chemists.

3 Research on Foods Containing Bubbles

Presentations that were directly related to bread covered a very diverse range of topics: image analysis; dough density and processing; bubble growth and disappearance; and dough rheology. These presentations will be discussed under two broad headings, which are explained below.

Measuring and determining the effect of processing on bubble structure (page 6).

Bubble research has benefited greatly from the increasing ability of computer technology in manipulating and analysing images. Capturing and analysing images of bubble structure from bread dough and bread slices can be done in a variety of ways. Bubble distribution data can be used to study the effect of bread processing, such as mixing of the dough, on final bread quality.

How bubble structure changes, and the role of dough rheology in bubble structure formation (page 10).

The bubble formation, aggregation and disappearance all influence the final baking quality of bread. It is known that the rheology of bread dough can be related to the final baking quality of the bread. An understanding of how dough rheology affects bubble growth and disappearance can be used to explain the way in which dough rheology controls bread quality.

3.1 Measuring and determining the effect of processing on bubble structure

In most avenues of scientific research much work is dedicated to developing better systems of measurement. The study of foods containing bubbles is no different, with several papers focusing specifically on measuring bubble structures and distributions.

– *"The imaging and measurement of bubbles in bread dough", Martin Whitworth & Juan Malava, CCFRA, UK.* [1]

Perhaps the most recent application of image analysis is studying the bubble structure of bread doughs. Unlike imaging baked bread slices, some degree of magnification is necessary to resolve the bubbles in non-fermented dough.

Doughs that have yet to be fermented are best assessed using scanning electron microscopy (SEM) or light microscopy. Preparing samples for both the light microscopy and SEM techniques involved freezing dough samples and then cutting thin 20 μm slices with a microtome. Preparation of dough slices for SEM resulted in a more textured appearance, which limited this technique's ability to reliably identify small bubbles. Thus SEM can resolve bubble diameters of 50 to 3500 μm, while light microscopy resolves smaller bubbles in the range 20 to 1500 μm. With light microscopy the large starch granules present in the samples transmitted light, making them difficult to distinguish from gas bubbles. One way of overcoming this problem is to use iodine to stain the starch granules. However, further work is needed to determine the reliability of iodine staining and overcome problems of the stain fading.

Preparing samples using freezing and slicing introduces some distortion of the sample visible in the magnified images. Large-scale distortions, such as tearing of the samples, can be ignored when the images are assessed using image analysis. Other less easily explainable distortions are seen, and are not simply due to the microtome squeezing the bubbles in the slicing direction. However, analysis of successive slices through the dough revealed that bubble sizes and positions are consistent across successive slices of dough samples. Thus distortions introduced by sample preparation have a negligible effect on the final information obtained on bubble structure.

Light or SEM microscopy cannot be used reliably to study fermenting dough, as the dough is too fragile to allow sample preparation without modification or destruction of the bubble structure. X-ray computerised tomography (CT) allows *in situ* determination of bubble structure in fermenting doughs. Bubbles larger than 1 mm can be imaged using X-ray CT.

– *"Imaging and measurement of bubbles in bread", Harry Sapirstein, University of Manitoba, Canada.* [2]

The first application that image analysis was applied to in bread research was in determining the bubble structure of bread crumb. Presently most existing bread image analysis techniques aim to provide a quality score for the bread crumb, mimicking the role of baker's trained eye. However, a great deal of quantitative information about bubble structure can be revealed using image analysis. For example, Harry Sapirstein's image analysis system determines a large range of cell parameters:

1. **crumb brightness**
   - mean gray level
2. **cell density**
   - number of cells per cm^2, higher values denote finer structure.
3. **mean cell area (mm^2)**
4. **mean cell equivalent diameter (μm)**
   - computed as $(area/\mu m)^{0.5}$
5. **mean cell wall thickness (μm)**
   - calculates the mean intercellular distance of adjacent cells sampled at 15° intervals around a centroid for each cell in image. The results are then averaged over all cells.
6. **crumb grain uniformity**
   - ratio of small-to-large cells using a threshold size of 4 mm^2, larger values denote more uniform cellular structure.
7. **number of moderately large cells**
   - $(7 < x < 25\ mm^2)$
8. **number of very large cells**
   - $(x \geq 25\ mm^2)$
9. **specific cell area**
   - percentage of total field of view occupied by detected cells.

Any image analysis of bubble structure requires the ability to distinguish between the air bubbles and the cell walls. This is known as image segmentation, and involves detecting the edge of air bubbles via defined threshold pixel intensity, or brightness. Regions of the image whose brightness is below the threshold level are classified as marking the end of the gas bubble and the start of the cell wall.

Selection of the threshold level is particularly critical to analysis of crumb images since the reflectance, and therefore crumb intensity or brightness, is proportional to the fineness of the bread crumb. Variations in the reflectance of bread slices from a single loaf can be of the order of 2-3% or higher. If the threshold intensity is not adjusted for each slice then this level of variation in reflectance can yield inaccurate crumb structure information. Thus, the threshold level should be determined for each image, rather than using a previously determined 'best' threshold value.

One way to determine the optimal threshold intensity for each image is to use a particular clustering algorithm, called the K-means algorithm. Comparing the fixed level threshold procedure with the K-means threshold procedure on bread made with and without oxidant reveals the inaccuracies inherit in using fixed level thresholds. For example, the K-means algorithm showed that addition of oxidants to the recipe decreases the thickness of the cell walls by 11%. However, the fixed level threshold procedure showed oxidants yielding 15% thicker cell walls. The latter result is clearly untenable given that oxidants are added to produce a finer textured crumb and therefore thinner cell wall structure.

To the non-expert observer, given the enormous dependence of image analysis on the edge detection or segmentation methodology used, then more rigorous comparisons of the various methods used should be made, and calibrated with other methods. Stereology is one technique against which image analysis techniques could be calibrated. Stereology involves individually, and manually, marking the positions of bubbles in an image on a vertical grid. The data are then used to calculate the various bubble dimensions, and bubble distribution. This technique has been used to study the bubble structure of freeze fracture samples of whipped cream [3]. One major advantage of this technique is that it provides an absolute assessment of the bubble structure which can then be compared to other image analysis techniques to determine which is the most accurate and reliable. Applying stereology to bread slices would be enormously laborious, restricting its use to comparing between image analysis techniques.

It is likely that there are many more bubbles in bread slices than are presently detected by image analysis, with bubbles less than 80 μm eluding detection[2]. Given that the smallest measurable bubbles in bread slice digital images (~160 μm) reside in the cell walls of neighbouring larger cells, then these smaller undetectable bubbles are also probably found within cell walls. These undetected gas bubbles are likely to have an enormous effect on the true bubble distribution of bread slices. Typical specific cell areas determined using image analysis are around 50%. Including an estimate of the effect of these undetectable cells increases specific cell area to 75 to 85%.

- *"Image analysis of food foams", Jan Cillers, Naheed Sadr-Kazemi, Grant Campbell, Satake Centre, UMIST, UK.* [4]

Image analysis of bread slices can reveal useful information about the effect of processing on bread quality, and how bakers and consumers assess bread quality. For example, bread is often mixed under partial vacuum to produce finer textured bread than attainable when mixing at atmospheric pressure. Analysis of the bread crumb revealed that the apparently coarser crumb of bread mixed at atmospheric pressure actually had a finer bubble size distribution. The atmosphere mixed bread contained 50% more of the finest bubbles than the bread mixed under partial vacuum. While the bubble size corresponding to 50% of the cumulative bubble size distribution for the vacuum mixed bread is double the size of the atmosphere mixed bread. Also the apparently finer textured vacuum mixed bread contained fewer gas bubbles than the bread mixed at atmospheric pressure (140 vs 207). However, bread mixed at atmospheric pressure contained a greater number of very large gas bubbles (cell areas around 1 mm^2) than in the vacuum mixed bread. It is the presence or absence of these very large bubbles that we use to visually assess the fineness of bread crumb.

"Entrainment and disentrainment of air during bread dough mixing, and their effect on scale-up of dough mixers." *Grant Campbell & Paras Shad, Satake Centre, UMIST, UK*[5]

While the method of mixing the bread dough can have a significant effect on the bubble structure of the final product, mixing also dictates the density of the freshly mixed dough (Table 1). Dough density has recently been studied to understand why large mixers produce more open, and therefore lower density, doughs than smaller versions of the same mixer design. If the reason for this can be understood it may be possible to design mixers that do not need the application of a partial vacuum at the end of the mixing cycle to produce a fine crumbed bread.

Table 1: Effect of mixing action on volume of air mixed into the dough.[6]

Mixer	Proportion of Gas by Volume (%)
Spiral	12-15
MDD + atmospheric pressure	8
MDD + partial vacuum	4
MDD + pressure	20+
Low Speed	3-5

Dough density is a function of the amount of air mixed into the dough during mixing, or air entrainment, and the amount of air lost from the dough, or, disentrainment. At present the mechanism of air disentrainment is not known. A mathematical description of the balance between air entrainment and disentrainment can be developed and then used to compare the mixing action of differently sized mixers. One such study focussed on why the larger 35 kg Tweedy mixer produces less dense doughs (11% air by volume) than its 1 kg Tweedy counterpart (7.5%).

When comparing mixers it is necessary to know the 'gas-free' density of the dough to calculate the rate of entrainment and disentrainment of air. The 'gas-free' density is the density that a dough would have if it were possible to make a dough without mixing in any air (eg under complete vacuum). The most accurate way of estimating the 'gas-free' density involves determining the density of doughs mixed under increasing levels of partial vacuum, then extrapolate back to the density at absolute zero pressure.

The comparisons between the two mixers showed that air mixed into the 35 kg Tweedy mixer had a greater residence time, 68 seconds, compared to 33 seconds with the 1 kg Tweedy. As the time the air spends in the dough increases with mixer size, the rates at which air enters and leaves the dough (entrainment and disentrainment) decreases in the larger mixer. However, the decrease in the rate of disentrainment is less than for entrainment, and so there is a net increase in the proportion of air in dough mixed on the larger mixer. By studying the effect of different mixer configurations and sizes it may be possible to create more efficient mixers. Intentionally adjusting dough density via mixer design rather than the more costly option of mixing under partial vacuum is one potential way of improving mixing efficiency.

3.2 How bubble structure changes, and the role of dough rheology

To understand how processing and ingredients affect bread quality requires an understanding of the physical properties of dough. Dough rheology is concerned with providing this information. Since bread is derived from dough foams, the contribution of dough rheology to the formation of this foam will provide important information about bread quality.

- *"Physical factors determining gas cell stability in a dough during bread making", Ton van Vliet, Wageningen Agricultural University, The Netherlands.* [7]

The formation of bread dough with a uniform distribution of small gas cells possessing very thin cell walls is dependent on Oswald ripening, equal growth of the gas cells, and gas cell coalescence during fermentation and baking. Oswald ripening, also known as disproportionation, is the growth of large gas bubbles at the expense of smaller ones. The physical properties of dough in relation to these three effects on bubble structure are likely to have a major influence on the final baking quality of the bread produced.

Oswald ripening

The difference between the internal pressure of the gas bubble and the surrounding material is known as the Laplace pressure. Laplace pressure is much higher in small bubbles than in large bubbles thus there is a driving force that causes the diffusion of gas from smaller to larger bubbles. Gas diffusion will continue until the smaller bubbles have disappeared.

Gas bubble growth due to CO_2 evolved from the respiring yeast, can only occur in existing gas bubbles of air, mostly N_2, trapped in the dough during mixing. The growth of these initial air bubbles during fermentation is delayed for about 30 minutes, as the CO_2, in the form of carbonic acid, first saturates the surrounding dough matrix before migrating into the gas bubbles. Thus, there is an extensive period of time in which Oswald ripening can effect the initial bubble size distribution of the dough before the dough starts to rise, with most of the small gas bubbles disappearing due to Oswald ripening.

As gas cells shrink the concentration of surface active components on the bubble wall surface will decrease, resulting in a decrease in the surface tension. Lowering surface tension reduces the Laplace pressure of the gas cell, slowing down Oswald ripening. The rate of change in the surface tension with changing cell wall area is known as the surface dilational modulus. It is thought that in bread doughs the surface dilational modulus is not sufficient to stop Oswald ripening, but it is sufficient to slow it down. However, at the latter stages of fermentation the Oswald ripening rate may increase as the gas bubbles come into increasing contact with each other.

Gas bubble growth involves biaxial extension of the surrounding dough, and these stresses will start to resist the growth of the gas bubble. The strain hardening behaviour of dough leads to greater resistance to bubble growth with increasing bubble size. Biaxial stresses and straining hardening behaviour of dough is thought to have a larger effect on Oswald ripening then the surface dilational modulus of dough. Strain hardening and biaxial stresses in dough may even stop Oswald ripening.

Equal growth of gas cells

As with Oswald ripening, the Laplace pressure of the bubbles' affects the rate at which they will grow in size as the CO_2 begins to fill them. Due to their lower Laplace pressure larger gas cells are preferentially filled by the CO_2 diffusing through from the dough. However, the surface dilational modulus and rheological properties of the dough surrounding the large gas bubbles will affect the Laplace pressure and therefore the rate of growth of the cell. Should these parameters be sufficiently large then they may retard the growth of the large gas bubbles until the smallest have growth to an equivalent size, leading to a more uniform distribution of bubble sizes in the dough.

Coalescence

Coalescence involves the merging of adjacent gas cells when the dough membrane separating them ruptures. Two mechanisms are most probably involved in the rupture of membranes separating neighbouring bubbles. Firstly the development of weak spots caused by local thinning of the membrane and, secondly, too small a rupture strain of the membrane. In the former case the strain hardening capability of the dough controls the thinning and therefore the development of weak spots in the dough. Such thinning of the membrane can be very significant with films as thin as a starch granule being observed separating gas cells in baked bread. The second mechanism relates to the physical limit to which the dough can undergo biaxial extension (strain) before it breaks and possibly relates to the bakers' concept of "extensibility".

Coalescence, equal cell growth and Oswald ripening all influence the production of good quality bread (Table 2). The importance of each of these mechanisms is not equal at each stage of breadmaking.

Table 2: Relationship between physical parameters of dough and the mechanisms affecting bubble structure.[7]

Physical parameter	Oswald ripening	Equal gas cell growth	Coalescence
Surface tension	Relevant	N/A	probably negligible
Surface dilational modulus	Relevant	Relevant	probably negligible
Biaxial stress	Relevant	Relevant	N/A
Strain hardening	Relevant	Relevant	Relevant
Fracture strain (in biaxial extension)	N/A [1]	N/A	Relevant

[1] N/A = Not Applicable

Many studies have related baking performance of flours to their bulk rheological characteristics, while the surface tension properties of wheats have received very little attention. One of the few studies that has been conducted found that surface tension and surface dilational modulus did not vary between four different cultivars. It may, however, be premature to eliminate the role that surface effects play in bread quality. Firstly, emulsifiers that are added to improve baking performance are known to have a clear affect on surface rheological properties and on Oswald ripening. Further, these emulsifiers do not affect strain hardening. Secondly, research efforts are focusing on surface active proteins present in bread doughs as a possible contributor to bread baking quality. Researchers at Reading University are attempting to determine whether the poor baking performance of wheats that have good rheological properties are due to surface active proteins such puroindolines.[8]

"Measurement of biaxial extensional rheological properties using bubble inflation & the stability of bubble expansion in bread doughs", Bogdan Dobraszczyk, University of Reading, UK.[9]

Despite the apparent importance of the rheological properties of dough in determining the formation of a dough foam, and therefore on the final baking quality of the bread, much of the rheological data are collected under the wrong conditions. Many attempts at collecting fundamental rheological information about doughs utilise shear and small deformations. Instead, data should be collected from doughs under extension (preferably biaxial extension), at large strains and low strain rates -- under the conditions dough experiences during breadmaking. Rheology of long chain high molecular weight polymer melts has shown at these materials exhibit strain hardening when tested under tension, but demonstrate shear thinning behaviour under shear.

While baking tests like the extensograph and alveograph test the dough under tension they are often conducted at excessively high strain rates and cannot be interpreted in fundamental rheological terms. The Dobraszczyk Dough Inflation System is one attempt to overcome these problems in an alveograph style inflation of a single bubble of dough.

Strain hardening is the increase in stress as a material undergoes greater levels of strain, and is characterised by a J-shaped stress-strain curve. Strain hardening is necessary in any operation that involves large extensions, such as metal forming, blow moulding plastic bottles, inflating plastic films, cold-drawing of polymer fibres and in biological materials. As mentioned earlier, the ability of strain hardening to resist further thinning of cell membranes by increasing resistance to deformation plays an important role in controlling Oswald ripening, coalescence and the equal growth of cells in bread doughs.

Further confirmation of the relationship between dough rheology and baking quality of flour was obtained with the Dobraszczyk biaxial inflation technique. Loaf volume was seen to increase with failure strain for a number of biscuit and breadmaking flours. The bubble failure strain is also highly correlated with the strain hardening index. The greater the strain hardening index the greater the strain hardening and the greater the strain at which bubble rupture occurs. Thus, the rheological property most strongly associated with baking quality, failure strain, is in turn related to the strain hardening properties of the flour.

4 Impact on CRC Science

The overriding importance of image analysis in the future of bread research was indicated by the three presentations which dealt specifically with the various techniques for imaging, and analysing, doughs and bread crumb. Information on the structure and distribution of bubbles in dough and crumb will provide useful insights into how bread structure evolves during processing. Image analysis will clearly be of increasing importance in future research conducted on cereals around the globe.

A less tangible, but possibly more significant, benefit of the Conference was that it focused specifically on bubble structure. Bubble structure creates the loaf volume and bread quality of the macro-scale, while protein, glutenin sub-units and other dough components combine, and are developed, to create a crumb structure. Thus, bubble structure is the link that binds the molecular action of dough components to the macroscopic scale of the baked bread.

One example of focusing dough research onto bubble structure would use the techniques developed by Megan Lindsay (doctoral project within CRC project 5.1.7). In this work, the position of specifically labeled protein groups within mixed dough is determined using confocal laser microscopy. This same approach could be used to look at the structure of proteins on the bubble cell walls of bread doughs.

Microscopy has equally useful scope in the study of dough rheology. When combined with rheological measurements, these techniques will provide a means of determining the effect of gas cells on the rheological properties of doughs. Such information will be of use in studying dough mixing, fermenting doughs, and the post-mixing stages of baking.

Ultimately, all research focusing on bread making must make some reference to dough and crumb bubble structure, even if it is only a passing analysis. However, it will be the areas of cereal chemistry, microscopy, rheology and processing research that will benefit most from direct analysis of bubble structure.

5 Acknowledgments

I would particularly like to thank the Quality Wheat CRC and Crop & Food Research for making attendance at the "Bubbles in Food" International Conference possible. Firstly, Dr Juliet Gerrard for making a substantial portion of a Crop & Food Research Outstanding Achievement Award, awarded to the "Dough development without oxidation" project team, available for my travel. And secondly, Dr Nigel Larsen for contributing additional monies to met the balance of the costs.

6 References

1. Whitworth, M., Malava, J. "The imaging and measurement of bubbles in bread doughs." Paper#15, Campden & Chorleywood Food Research Association, United Kingdom.
2. Sapirstein, H."Imaging and measurement of bubbles in bread." Paper#16, University of Manitoba, Canada.
3. Smith, A., Goff, D., Kakuda, Y. "Quantitative stereology used to measure the effect of heat treatment and stabilizer on whipped cream structure." Paper#11, University of Guelph, Canada.
4. Cilliers, J., Sadr-Kazemi, N., Campbell, G."Image analysis of food foams." Paper#17, UMIST, United Kingdom.
5. Campbell, G., Shah, P. "Entrainment and disentrainment of air during bread dough mixing, and their effect on scale-up of dough mixers." Paper #2, UMIST, United Kingdom.
6. Cauvain, S. "The evolution of bubble structure in bread doughs and its effect on bread structure." Paper #7, Campden & Chorleywood Food Research Association, United Kingdom.
7. Vliet, T. van "Physical factors determining gas cell stability in a dough during bread making." Paper#10, Wageningen Centre for Food Sciences, The Netherlands.
8. Gan, Z., Graaf, van der J., Leonard, S. , Brooker, B., Parker, M., and Schofield, J. "Role of wheat proteins and polar lipids in the stabilisation of the foam structure of dough." Poster Paper #7, University of Reading & Institute of Food Research, Reading, United Kingdom.
9. Dobraszczyk, B. "Measurement of biaxial extensional rheological properties using bubble inflation & the stability of bubble expansion in bread doughs." Paper#14, University of Reading, United Kingdom.

7 Appendix I: Presentations

The following is a list of the oral presentations made at the conference, only the presenting author is listed with the paper title.

1. Fundamentals of bubble mechanics in foods
K Niranjan, University of Reading, UK

2. Entrainment and disentrainment of air during bread dough mixing, and their effect on scale-up of dough mixers
Grant Campbell, UMIST, UK

3. Foaming of ice cream and the time stability of its bubble size distribution
Hiltrud Rohenkohl, Institute fur Lebensmitteltechnik eV, Germany

4. Foam generation in a continuous rotor/stator mixer
W Hanselmann, Nestle R&D Centre Welding, Switzerland

5. Conjugated effects of substrate and process parameters in food foaming processes
G. Djelveh, Universite Blaise Pascal, France

6. Vapour-induced puffing as an intermediate step in the dehydration of vegetables
Nick Shilton, University College, Dublin, Ireland

7. The evolution of bubble structure in bread doughs and its effect on bread structure
Stan Cauvain, CCFRA, UK

8. Simulation of bubble growth in heat-processed cereal systems
John Mitchell, University of Nottingham, UK

9. Prediction of dough volume development which considers the biaxial extensional growth of cells
Hsimin Huangi, Centre for Advanced Food Technology, USA

10. Physical factors determining gas cell stability in a dough during bread making
T van Vliet, Wageningen Centre for Food Sciences, The Netherlands

11. Quantitative stereology to assess the structural stability of whipped cream
Alexandra Smith, University of Guelph, Canada

12. Keeping ahead - optimising beer foam performance
Paul Hughes, Brewing Research International, UK

13. Enhancement of bubble surface elasticity by crosslinking agents and the effects on protein foam stability
Peter Wilde, IFR Norwich, UK

14. Measurement of biaxial extensional rheological properties using bubble inflation & the stability of bubble expansion in bread doughs
Bogdan Dobraszczyk, University of Reading, UK

15. The imaging and measurement of bubbles in bread doughs
Martin Whitworth, CCFRA, UK

16. Imaging and measurement of bubbles in bread
Harry Sapirstein, University of Manitoba, Canada

17. Image analysis of food foams
Jan Cilliers, UMIST, UK

18. Beer fermentation activity estimation using information about aeration conditions and fuzzy knowledge processing
Svetla Vassileva, Bulgarian Academy of Agricultural Sciences, Bulgaria
<<Not presented>>

19. Birth and development of the Widget
Jeremy Browne, Guinness Packaging, UK

20. Influence of aeration and emulsifier level on cake batter rheology
Sarab Sahi, CCFRA, UK

21. Measurement of gas phase morphology in ice cream
Susie Turan, Unilever Research, UK

22. Can starches help to develop the next generation of aerated dairy desserts?
Francoise van Heeswijk, National Starch

23. What causes the tingle in carbonated drinks?
Earl Carstens, University of California, Davis, USA

24. Recent progress in our understanding of Champagne wines foaming properties
Bertrande Robillard, Moet and Chandon, France

25. Shortbread textures with electrical processing
L Jamieson, EA Technologies, England

8 Appendix II: Poster papers

1 Effect of fermentation on bubble formation and structural properties of extruded cereal products
A Plunkett, Manchester Metropolitan University, UK

2 Effect of mixing energy input on bubble formation and puffing of waxy rice dough
Gihyng Ryu, Kongju National University, Korea

3 Bubble formation and gas dissolution with CO_2 in water
B Jefferson, G Barker and S Judd, Cranfield University, UK

4 Air inclusion mechanism and bubble dynamics in intermediate viscosity food systems
Adrian Massey and K Niranjan, University of Reading, UK

5 The role of wheat proteins and polar lipids in the stabilisation of the foam structure of dough
Z Gan, J van der Graaf, SA Leonard, BE Brooker, ML Parker and JD Schofield, University of Reading and Institute of Food Research, UK

6 Ostwald ripening and equal growth of gas cells in flour doughs
B Dunnewind and T van Vliet, Wageningen Agricultural University, The Netherlands

7 Cava sparkling wine foaming properties: modifications due to variety and aging
Cristina Andres-Lacueva, Rosa Lamuela-Raventus, Susana Buxaderas and M del Carmen de la Torre-Boronat, Universitat de Barcelona, Spain

8 Caseinate submicelle layering in foam films: effects of intrinsic lipid contamination
Fiona Husband and Peter Wilde, Institute of Food Research, Norwich, UK

9 Effects of sugars on the foaming of native and dried proteins
Hong-Jen Liang and Brent S Murray, University of Leeds, UK

10 Modelling bubble growth during proving of bread dough: predicting the output from the Chopin Rheofermentometer
Paras Shah, Grant Campbell, Christine Dale and Alison Rudder, UMIST, Manchester and University of Salford, Salford, UK

11 Influence of aeration conditions on morphological characteristics of batch yeast cultures in sparkling wine production studied by soft computing methods
Svetla Vassileva, Ognyan Tzvetanov, Jana Angelova, Institute of Control and System Research, Sofia, Bulgaria

12 Study of the sparkling wine composition and quality using a neuro-fuzzy knowledge based system
Svetla Vassileva, Ognyan Tzvetanov, Jana Angelova, Institute of Control and System Research, Sofia, Bulgaria

13 Improved methods for measuring foam characteristics of proteins
A Phianmongkhol and J Varley, University of Reading, UK

14 IFD: In-line foam detection and analysis using artificial vision techniques
S Lemieux, W Matthes-Sears, D Labelle, J Pomeroy, Canada

15 Reconstruction of bubble size distributions from slices
GM Campbell, CD Rielly, PJ Fryer, and PA Sadd, UMIST, UK

16 Fat emulsifiers and their functionality in cake batters
Juan M Alava, Martin B Whitworth, Sarabjit S Sahi and Paul F Catterall, CCFRA, UK

17 The stiffness versus porosity relationship in infrared heat treated (micronized) durum wheat grains
Martin G Scanlon, Kevin I Segall and Stefan Cenkowski, University of Manitoba, Canada

18 Foaming of monovarietal white wines
Magdalena Lupez-Barajas, Elvira Lupex-Tamames and Susana Buxaderas, Universitat de Barcelona, Spain

19 The application of the gas laws and traditional mass transfer theory in a modern food manufacturing environment
Craig Whitwam and George Hayes, Manchester Metropolitan University, England

20 Bubble growth during proving of bread
Paras Shah, Grant M Campbell, Christine Dale and Alison Rudder, UMIST and University of Salford, England

21 Impeller-induced deaeration of viscous foods
T Cabaroglu, K Niranjan and AS Khare, University of Reading, UK

22 Bubble evolution in beer fermentation
Severino Pandiella, UMIST, UK