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Aeration and rheology of bran-enriched bread dough during sheeting

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Copyright statement

Abstract

Bread quality depends on the aerated structure of the baked loaf, which arises from the unique rheology of wheat flour doughs as a result of the viscoelastic behaviour of wheat gluten proteins. Development of this dough structure is an essential element of dough preparation, generally achieved in modern processes via high speed mixing; however, sheeting of doughs is potentially a more effective and energy efficient approach that gives superior bread quality. Meanwhile, inclusion of bran in the dough formulation enhances the healthiness of bread, but hinders the development of the gluten structure and the resulting quality and palatability of the bread. Using sheeting to enhance dough development could help to offset the damaging effects of bran and allow production of more appealing high fibre breads. Implementing sheeting in a commercial breadmaking operation is more difficult than the use of high-speed mixing; however, recently there have been moves to implement this technology commercially. There is therefore a need to understand in greater detail the development of bread dough by sheeting, and its interactions with bran and with the development of the aerated structure of bread.

The effects of roll gap and number of sheeting passes on dough development with or without bran were studied using two different mixers, the MajorPin mixer and the Tweedy 1 mixer. The maximum expansion capacity of yeasted doughs was measured using the Dynamic Dough Density (DDD) test, which is a sensitive indicator of the degree of development of the dough’s gluten structure. The effects of the level (5, 10 and 15%) and particle size (Coarse, Medium and Fine) of bran on dough development by sheeting were investigated by measuring maximum expansion using the DDD system and by measuring the springback of dough following sheeting. Effects on bread quality were assessed by measuring the volume of baked loaves using an EinScan 3D scanning system, and crumb structure quantified by texture analysis and by image analysis using the C-Cell bread analysis system. Effects of wheat bran level and particle size on water absorption were investigated using the Chopin Mixolab 2.

Sheeting of doughs without bran for up to 12 sheeting passes increased maximum expansion and springback for roll gaps of 6, 9 and 12 mm. In doughs with bran, maximum expansion and springback increased from 4 to 8 passes, then decreased following 12 sheeting passes, for roll gaps of 6, 9 and 12 mm. At 15% bran, maximum expansion and springback decreased, more for Fine bran particles than for Medium and Coarse bran. Fine bran was consistently the most damaging to expansion and springback, while Medium bran was consistently the least damaging, with Coarse in between. The consistency of these patterns across all the conditions indicates that there is an intermediate particle size and an intermediate number of sheeting passes that maximise gluten development. There is thus scope for bakers to optimise the development of doughs containing bran, by adjusting bran particle size and sheeting, in order to minimise the detrimental effects of bran on bread quality.

The effects of sheeting on expansion capacity during proving translated into effects on final baked loaf volume and hardness. Control doughs without bran gave the largest loaf volumes, and volume increased by around 10-13% as sheeting increased from 4 to 8 to 12 passes at roll gaps of 6 and 12 mm. Loaves were slightly larger after sheeting at a 6 mm roll gap, reflecting greater gluten development at the smaller gap. Bran decreased

loaf volume, with Fine bran once again the most damaging and Medium bran the least, and with sheeting for 8 passes once again optimal compared with 4 or 12 passes. Despite the detrimental effects of adding bran, sheeting is effective in alleviating these effects by enhancing the development of the dough.

C-Cell and EinScan results showed that sheeting and the addition of bran affect the volume and structure of the final baked bread. At both roll gaps, 6 and 12 mm, the control bread without bran had a higher number of cells as sheeting increased from 4 to 8 to 12 passes, and the diameter and wall thickness of the cells was lower. Sheeting doughs with bran increased the number of gas cells in the baked loaf from 4 to 8 passes, but the number then decreased at 12 passes for all particle sizes of bran. Fine bran gave more cells than the Medium and Coarse bran, the latter giving the lowest number of cells with larger diameters and wall thicknesses, indicating a more open crumb structure.

Mixolab results showed that addition of bran increases water absorption. This effect increases with the increase in the level of bran and with the decrease in its particle size. The lowest Mixolab water absorption was recorded for the Coarse bran, which suggests that the time required to absorb water by large bran particles is longer than for smaller particles, which results in an increase in the development time of the dough and decreases the stability time.

The current work has expanded understanding of the effects of roll gap and sheeting on dough development with or without bran and on the quality of final baked bread, in order ultimately to enhance the commercial application of sheeting for bread manufacture.

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List of abbreviations

AACC	American Association of Cereal Chemists
ANOVA	analysis of variance
BSD	Bubble Size Distributions
CBP	Chorleywood Bread Process
DDD	Dynamic Dough Density
HSE	Health Survey for England
LSV	Loaf Specific Volume
MDD	Mechanical Dough Development
MRI	Magnetic Resonance Imaging
WAC	Water Absorption Capacity
C1 (Nm)	Maximum torque during mixing, torque at the end of the holding time at 30 °C
C2 (Nm)	Minimum consistency, the minimum value of torque produced by dough passage while being subjected to mechanical and thermal constraints
C3 (Nm)	Peak torque the maximum torque produced during the heating
C4 (Nm)	Minimum torque reached during cooling to 50 °C breakdown torque
C5 (Nm)	Final torque, the torque after cooling at 50 °C

Chapter 1. Aeration of bread

1.1 Dough aeration and rheology

Aeration and rheology of dough are fundamental for breadmaking to create the distinctive and appealing structure of bread (Campbell & Martin, 2012, 2020). Aeration imparts key quality characteristics of bread products such as their volume and distinctive forms. During the mixing operation, bubble nuclei are formed that also provide oxygen for dough development, while during proving these nuclei are inflated with carbon dioxide produced by yeast. The unique rheology of dough helps to retain these bubbles to create a well-risen dough piece. The rheological properties that result from the presence of the unique gluten proteins in wheat flour help to make the aerated structure possible. When the development of the flour-water mixture occurs in the dough, a viscoelastic network is formed from the gluten. This network can trap and retain the gas bubbles (Hlynka, 1970; Noel & Brownsey, 1990). Many methods have been applied to explain the origins of dough rheology and its relevance concerning bread quality, and the mechanisms of aeration during the stages of breadmaking. Through a focus on aeration and rheology, many bread studies have been invigorated and new scientific insights and industrial applications encouraged. With all the methods and ideas related to aeration and rheology, there is scope to continue to improve the quality of bread products, as well as the ability to make improvements to the diverse range of bakery products.

Rheology and aeration interact during the breadmaking process. Figure 1.1 shows a representation of the breadmaking process that highlights these interactions. Most of the control of bread quality occurs at the mixing step. The initial three decisions made by a baker in preparing to manufacture bread are: what dough formulation to use; what mixer to use; and how to operate the mixer. Figure 1.1 illustrates the interactions in the mixer and then with proving and baking. Regarding mechanical dough development (MDD) processes such as the Chorleywood Breadmaking Process (CBP), the aims of mixing are to develop the dough's rheology and to aerate it. By dough development (labelled 1 in Figure 1.1), it is meant that the gluten network structure is developed through the alignment of the gluten proteins to allow long-range viscoelastic interactions (2). This is apparent as alterations in the bulk rheology of the dough (3), as illustrated by, for instance, Farinograph curves that measure bulk rheological differences. The bulk rheology affects the aeration (4); for example, less gas is entrained during mixing when using strong flours with a higher protein content, resulting in stiffer doughs. However, the observed bulk rheology is influenced by the presence of bubbles; the interaction at this stage is bi-directional. Meanwhile, dough development is also influenced by aeration (back to 1 again) to participate in oxidation reactions via dehydro-ascorbic acid by providing atmospheric oxygen (Chin et al., 2004; Chin & Campbell, 2005b; Chin et al., 2005). Thus the design and operation of the mixer and the dough formulation influence the interactions during mixing and hence the final bread quality.

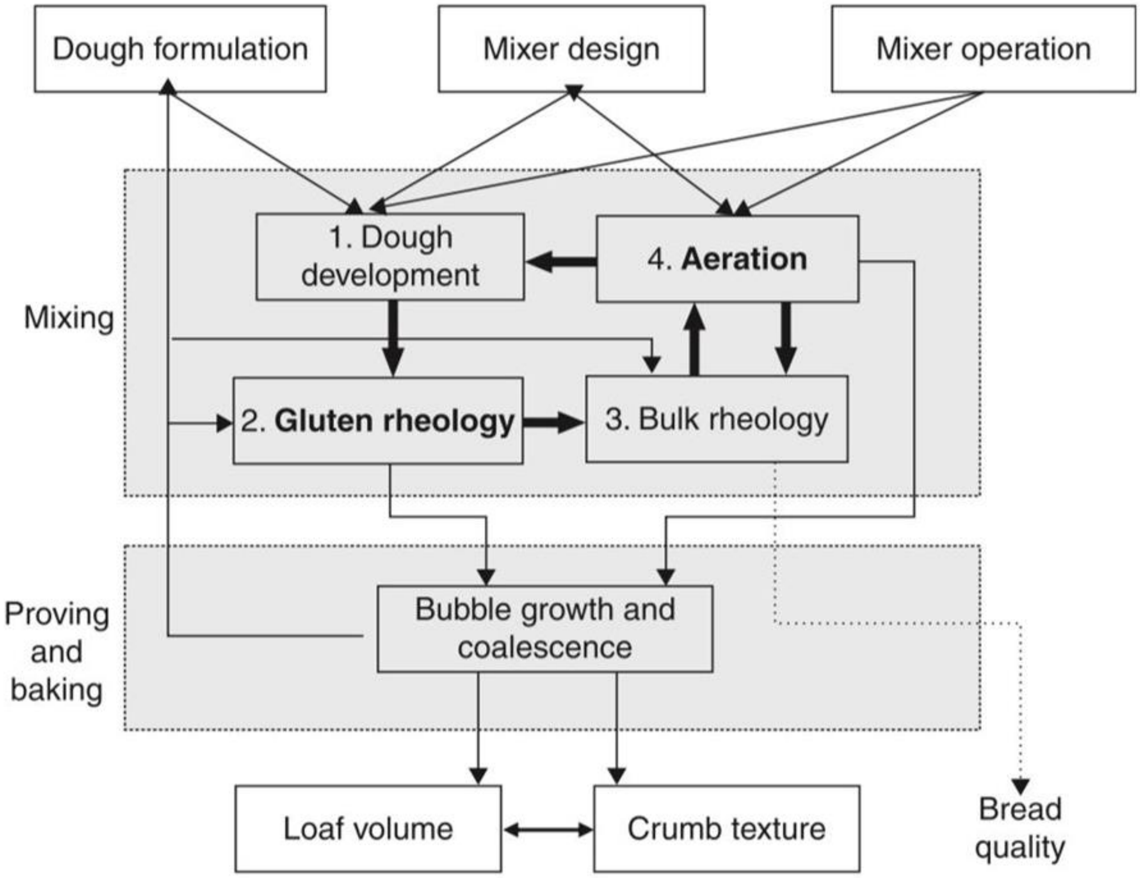


Figure 1.1 Effects of dough formulation, mixer design and mixer operation, on interactions between aeration and rheology during mixing, proving and baking (Campbell & Martin, 2020).

Once the rheological character of the dough and its aerated structure have been set by the formulation and mixing, the subsequent development of the dough during proving and baking is largely deterministic; the bubbles grow and coalesce in ways dictated by their initial size and number and by the dough rheology, influenced by the changing temperatures and by the constraints of the baking tin (Campbell & Martin, 2012, 2020; Chin et al., 2004, 2005; Chin and Campbell, 2005a, b).

During these stages, some ingredients (sugar and yeast for example) in the dough formulation also exercise their effects. The growth of the bubbles and the extent of coalescence determine the final baked loaf size and bread structure (Campbell & Martin, 2012, 2020).

In the context of the current work, Figure 1.1 could be adapted to include sheeting along with mixing as a means of developing and aerating the dough, while bran is part of the dough formulation that affects aeration and gluten development during mixing, and the subsequent growth and coalescence of the bubbles during proving and baking.

It is established that there is a relationship between the bulk dough rheology and the quality of baked loaf based on the unique rheology of the bread dough that allows for the production of raised bread, as shown by the dotted arrow on Figure 1.1. Studies try to link measurements of the bulk rheology and the quality of the final baked loaf bread by understanding the interpretation of the meaning of the measurements and how these measurements translate mechanistically to dough behaviour and final loaf structure. "But it is gluten rheology that is actually at the heart of the ability to make bread; bulk rheology is only a proxy for gluten rheology and is influenced by aeration of the dough. Factors affecting measured bulk rheology may be affecting aeration rather than gluten rheology" (Campbell & Martin, 2012, 2020; Chin et al., 2004, 2005; Chin and Campbell, 2005a, b).

The formation of an aerated structure in the final bread is a crucial feature of breadmaking. Numerous general and speciality breads are distinguished by characteristic aerated structures that are achieved by the integration and manipulation of bubbles in the dough throughout mixing and proving processes, and their transformation into interconnected gas cells in the bread during baking (Campbell & Martin, 2012, 2020).

Bubbles grow not only in bread doughs and cakes. In systems ranging from polymer foams (Han & Yoo, 1981) and dry-process photography (Barlow & Langlois, 1962) to magmas (Proussevitch & Sahagian, 1998), bubble growth has attracted scientific interest, and a fundamental body of research exists.

In bread the leavening action arises through carbon dioxide production from yeast, while in cakes and other baked goods, CO_2 production is from chemical agents such as baking soda (sodium bicarbonate) in the presence of acidic ingredients or baking powder in which the acid in incorporated. During manufacture, initially the bubble growth is by this chemical or biological CO_2 creation, thereafter by evaporation and gas expansion resulting from the heat of baking. To obtain a high volume of bread with a fine aerated structure, both the incorporation and the stability of gas bubbles are critical. Extensive investigation of the development of bubbles during breadmaking phases in traditional wheat-based bread systems has been conducted (Chiotellis & Campbell, 2003a; Dobraszczyk, 1997; Dobraszczyk & Morgenstern, 2003; Dobraszczyk & Salmanowicz, 2008; Dobraszczyk, 2004; Shah et al., 1998). Because sufferers of coeliac disease must avoid gluten, a lot of research has also been dedicated to gluten-free breads and bakery products (Gallagher et al., 2004; Marco & Rosell, 2008; van Riemsdijk et al., 2011) but the stabilization and retention of gas without gluten is very challenging.

Some of the most important features of high-quality bread that are desired by consumers are the following:

1- The number of cells in the crumbs and their optimal distribution gives good properties to bread. These cells arise from trapped gas pockets during mixing and are manipulated throughout the bread making process to achieve bread of the desired properties.

2- A high volume loaf with a fine crumb structure is a desirable characteristic. As bread is sold by weight, a larger volume is indicative of more bread and a light texture.

3- Bright bread, in particular in white bread. The orientation of cells revealed on a slice affects how much light is reflected from them and thus how bright the bread appears.

4- Soft bread is another key quality characteristic that is perceived by consumers as indicative of fresh bread.

These parameters are determined by consumers by the extent to which the cells are distributed in the bread and their effect on the eating qualities of the bread, the weight of the bread, how well it slices and how well it mops up a sauce (Cauvain, 2015).

1.2 Sheeting of bread doughs

The purpose of mechanical dough development using high-speed mixing is to develop the gluten structure in order to enhance the retention of gas during proving and baking and the production of baked loaves with a large volume and fine crumb structure. However, intense mechanical mixing is expensive in terms of energy usage. Chin and

Campbell (2005a) estimated at that time that the annual cost of electricity to operate all the dough mixers in the UK was £5 million; with increases in energy prices over the last decade, the current figure would probably be at least double this.

Kilborn and Tipples (1974) demonstrated that dough development by sheeting (i.e. passing the dough repeatedly between pairs of counter-rotating rollers) was much more energy efficient than mechanical dough development. They estimated that developing doughs by sheeting used only about 15% of the energy of high-speed mixing to achieve similar levels of development and bread quality. The reason for the greater efficiency is the highly directional nature of sheeting, which aligns gluten proteins more effectively than the more random motion that occurs in a dough mixer. Implementation of sheeting in a commercial production facility is much less easy than development in a mixer, hence this finding was not taken up commercially at the time. However, in recent years, with advances in dough handling equipment and with efforts to reduce energy usage in breadmaking and to increase bread quality, use of sheeting to develop doughs has been revisited. The current project therefore took the opportunity to investigate the development of dough structure by sheeting, using techniques that were not available back in 1974, to give a deeper understanding of the nature of dough development by sheeting and how best to exploit this technology and maximise its benefits for bread quality and energy efficiency.

During the sheeting process, the thickness of the dough piece can be reduced by up to one-tenth and the surface area increased by a factor of more than three times. This process dramatically reformats the dough structure. This process aims to extend the structure of dough and to close the open cells that were created during the mixing process. Sheeting is not able to degas the piece of bread dough unless the dough contains some large gas cells (as distinct from bubbles that will become large cells). These bubbles are formed during the initial proving process and resulting from the improper distribution of the dough components during mixing or insufficient degassing of the fermented doughs during dividing and rounding. Although there is little evidence of creating some gas cells during sheeting, reworking has an essential role in breaking some walls between cells. In contrast, others should be stretched or significantly reduced (Cauvain, 2015).

Table 1.1 show the effect sheeting on gas volume in dough prepared in different ways. Doughs prepared by the bulk fermentation method have the advantage of containing large quantities of gas compared to modern no-time doughs that contain much less gas inside when they reach the divider. Depending on how the dough is prepared, the maximum volume of gas with the modern no-time doughs (CBP and Spiral) is within 20%, while it reaches 70% in the case of the dough of bulk fermentation (Table 1.1). With the arrival of the dough to the moulding/sheeting stage, the gas volume limits are 17-18% for no-time doughs and about 25% for bulk fermentation doughs. Through this data, it is clear that there is a large degassing of bulk fermentation doughs compared with modern no-time doughs in which the gas is kept essentially unchanged (Cauvain, 2015).

Table 1.1 Effect of sheeting on gas volume in dough, (Cauvain, 2015).

Dough Processing	Proportion of gas by Volume (%)		
	Fermented	CBP	Spiral
End Mixing	5	5	7
End Fermentation	70	-	-
End first Proof	27	16	18
End Moulding/Sheeting	18	15	17

1.3 Bran in bread

Wholemeal and high fibre bread is an important component of the bakery sector, but the addition of bran to the dough formulation decreases dough expansion and final baked loaf quality (Campbell, al., 2008a; de Kock et al., 1999; Galliard, 1986b; Lai, Hoseney, et al., 1989a, 1989b; Özboy & Köksel, 1997; Pomeranz et al., 1977; Seyer & Gélinas, 2009; Shogren et al., 1980; Zhang & Moore, 1997; Zhang & Moore, 1999). The superior gluten development achieved by sheeting may offer an important solution to lower the quality of high fibre bread.

Bakers and bread manufacturers produce different types of fibre-rich bread with bread. Wholemeal bread is one of the most important of them, which uses 100% of the wheat grain, so nothing added or taken away. Brown bread is another fibre-rich product, and flour contains 85% of the wheat grain, such that not all of the bran and germ have been removed. Brown flour can also be manufactured by adding wheat bran to white flour in different concentrations up to 15% and depending on the type of bread to be manufactured. Wholegrain bread is also produced, which has a dense wholemeal flour base and well as lots of grain and seeds by up to 14%. They contain the entire grain: the bran (outer layer), endosperm (starchy middle layer) and germ (nutrient-rich inner part) (Streit, 2019).

It is recommended to eat bread as part of a healthy diet in the USDA Food Guide, the Canadian Food Guide, and the UK's Right Eating Pyramid (Federation of Bakers, 2018), as bread is the largest food group, being healthy and nutritious. Bread is a staple and traditional in the UK in almost every family. 99% of UK households buy bread, and the equivalent of almost 12 million loaves are sold daily (Anon, 2012a). White bread, which is the most consumed in the United Kingdom, reached about 18 million consumers in 2019, followed by brown bread/wholegrain, where the number of consumers reached 15.5 million in the same year (Statista, 2021).

The statistics also showed the average purchase of bread per person per week in the United Kingdom in 2019/2018. The standard cut white bread is the most frequently purchased type of bread, weighing 172 grams per person per week, followed by whole wheat bread and grain bread weighing 113 grams. According to consumer market expectations, the size of the bread market in the United Kingdom reached about 2130 million kilograms in 2019, and by 2025 it is expected that the size of this market will increase to about 2194 million kilograms (Statista, 2021).

Adding bran and artificial fibre to the most consumed white flour enhances and contributes to the production of healthier bread (Chin, 2003; Dukes et al., 1995). As is the case with fibre, especially brown bread and wholegrain bread, which contains large levels of fibre and is important and healthy to get rid of body waste, which leads to a healthy intestine (Chin, 2003). Recently, other types of cereal flour such as oats, barley and rye have been introduced for the sake of diversified production of bread (Chin, 2003; Drzikova et al., 2005). This results from increasing awareness and health concerns of celiac disease (Chin, 2003; Drzikova et al., 2005).

Aeration of dough enriched with bran is considered a challenge, and the biggest challenge is to know how the added bran particles affect the obstruction of ventilation in the dough and how this can be reduced. The detrimental effects of bran on bread dough and a deeper explanation thereof is still unclear, although research has been conducted in this area for many years (de Kock et al., 1999; Shetlar & Lyman, 1944). Various mechanisms have been suggested, involving two main categories of effects, physical and chemical (de Kock et al., 1999). More studies on this will provide us with a clear explanation of why brown bread or whole grain bread is less desirable by consumers. There are some factors that can be attributed to the differences in research results, which are represented in the difference in natural variation in composition and physical properties and variation in breadmaking production and in reparations made (Noort et al., 2010; Zhang & Moore, 1997).

The common belief in regard to the presence of bran particles in dough formulations is the destructive effect of this bran on the surface, and then the structure of the whole dough. The occurrence of this disruption maybe during the mixing process, during the slow expansion of the proving stage (Pomeranz et al., 1977; Wootton & Shams-Ud-Din, 1986) or during the baking stage in which the most rapid changes occur (Gan et al., 1992; Pomeranz et al., 1977; Shetlar & Lyman, 1944; Wootton & Shams-Ud-Din, 1986; Zhang & Moore, 1997). This physical disruption to the dough structure can be reduced using pearling of wheat kernels, which removes epicarp hairs, components that may be particularly damaging to the structure of gluten films within the dough (Gan et al., 1992).

The current work thus extended the study of sheeting of white flour doughs to investigate the effects of adding bran to the dough formulation.

1.4 Scope of the dissertation

Bread quality depends on the aerated structure of the baked loaf, which arises from the unique rheology of wheat flour doughs as a result of the viscoelastic behaviour of wheat gluten proteins. Bread dough is aerated during mixing and those bubbles are inflated with carbon dioxide produced by yeast during proving, and further inflated via steam production and thermal expansion of gases during baking. The extent of gas retention and gas cell coalescence depends on the gluten structure, while gluten development and dough rheology themselves depend on aeration of the dough; there is a bi-directional interaction between dough aeration and rheology (Campbell & Martin, 2012). Understanding this relationship has been a major focus of bread research in recent decades.

Mechanical dough development uses intense high speed mixing to develop the dough structure so that it retains gas more effectively and gives larger loaves with finer aerated structures. However, sheeting doughs between pairs of rollers is a more energy efficient way of developing the dough structure and can give superior bread quality. Implementing sheeting in a commerical breadmaking operation is more difficult than the use of high-speed mixing; however recently there have been moves to implement this technology commercially. There is therefore a need to understand the development of bread dough by sheeting, and its interactions with aeration and with bran, in greater detail, and this forms the focus of the current research.

Chapter 2 presents an overview of gas phase behaviour in the dough during the phases of breadmaking as well as the impact of each stage on the development of bread dough, in order to provide the detailed understanding of the current state of knowledge about bread dough aeration and rheology.

Chapter 3 introduces sheeting of doughs in the context of breadmaking, and how sheeting affects the development of bread dough. This leads to the objectives of the current work, to apply a unique method available in our labs, Dynamic Dough Density, along with other techniques to investigate the effectiveness of sheeting to develop the ability of doughs, with and without added, bran, to retain gas. Chapter 4 then presents the background literature relevant to understanding bran in bread.

Chapter 5 describes in detail the materials, equipment and procedures used in performing the studies of dough sheeting and gas retention.

Chapter 6 presents the results of effect of sheeting on white flour doughs prepared using two different mixers, the Majorpin mixer and the Tweedy 1 mixer, in order to quantify how the sheeting regime (roll gap and number of passes) affects the development of the dough.

Chapter 7 investigates the interactions between bran and sheeting and their effects on dough expansion and baked loaf volume and structure.

Chapter 8 presents studies using a Chopin Mixolab to investigate the effects of bran on the water absorption of dough formulations and the effects on dough processing during mixing and heating.

Chapter 9 concludes the thesis by summarising the main findings from the current work and presenting recommendations for progressing research in this area, in order to establish the importance of sheeting in improving and developing the quality of bread and its products.

Chapter 2. Behaviour of the gas phase in dough during the stages of breadmaking

2.1 Introduction

Gas phase behaviour in bread was studied directly for the first time in the 1930s and 1940s by Baker and Mize (Baker, 1941; Baker & Mize, 1937, 1939, 1942, 1946). They demonstrated that the gas cells that appear in bread are originally created as bubbles in the dough during mixing. They also showed that there was a coincidence between aeration and dough development (maximum aeration occurs during mixing when the dough is at its point of peak development, in the mixers they used), and that the dough development is affected directly by the gas pressure and composition in the headspace during mixing.

This chapter provides an overview of research that has been done since these pioneering studies, leading to the current knowledge base and understanding of aeration and rheology during bread dough mixing, proving and baking.

2.2 Industrial breadmaking

Breadmaking is a series of aeration stages (Campbell et al., 1998). All breadmaking processes mainly rely on a small number of basic steps as in Figure (2.1), and consecutively these are Mixing, Moulding, Proving and Baking, where each stage involves the manipulation and retention of the gas cells in a suitable form until the product is baked

(Grenier et al., 2003). Figure 2.1 shows the breadmaking steps, which are explained in detail in the following sections.

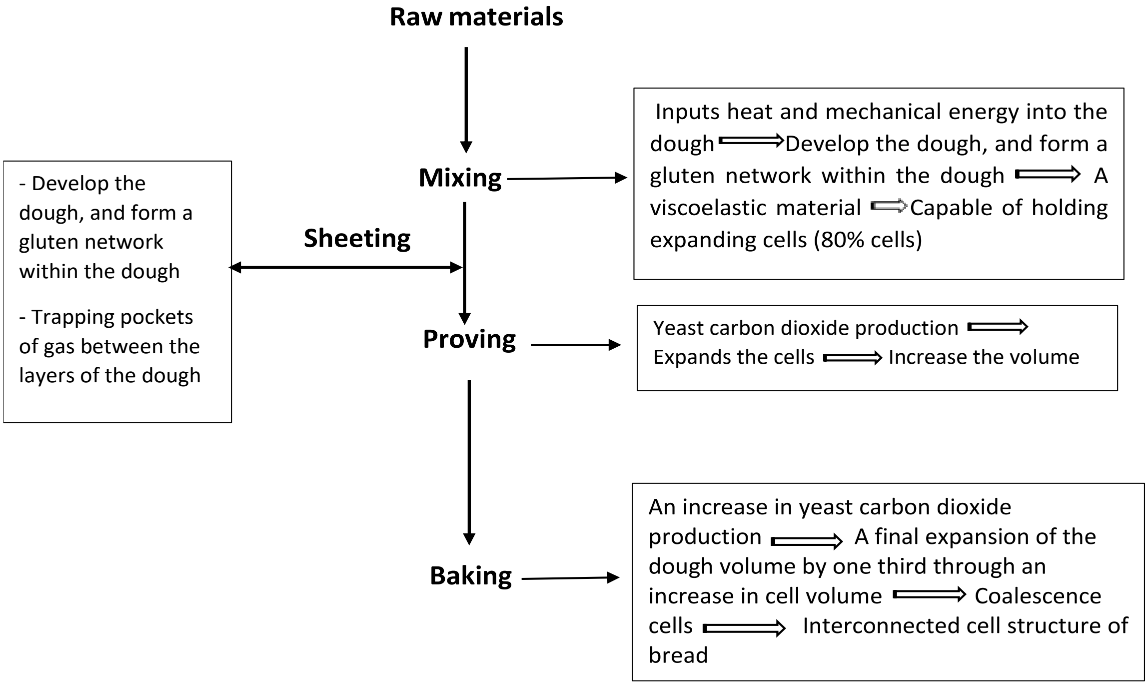


Figure 2.1 Main stages involved in a breadmaking process.

2.2.1 The Chorleywood Breadmaking Process

Although bread can be made in several ways, industrially there are two main methods of making bread: the bulk fermentation process and the CBP. For nearly six decades, CBP has now been adopted in many parts of the world from Australia to South Africa, Turkey and even France, where some stick loaves are made the Chorleywood way, although not for the classic French baguette.

The Chorleywood Bread Process (CBP) is one of the predominant breadmaking process in the UK (Cauvain & Young, 2006a). Bender (2016, p 59) introduces the CBP as follows: "The Chorleywood Bread Process is a method of preparing dough for bread making by submitting it to intense mechanical working, so that, together with the aid of oxidizing agents, the need for bulk fermentation of the dough is eliminated. This is a so-called 'no-time' process and saves 1½–2 hours in the process, permits the use of an increased proportion of weaker flour, and produces a softer, finer loaf, which stales more slowly. Named after the British Baking Industries Research Association at Chorleywood."

In 1958 the essential factors in mechanical dough development (MDD) began to be investigated at Chorleywood by the British Baking Industries Research Association (that later became the Flour Milling and Baking Research Association, then joined Campden Food and Drink Research Association to form the Campden & Chorleywood Food Research Association, now called Campden-BRI). The purpose of that work was to develop a new process of mechanical dough development, which has now stood the test of time to become the predominant breadmaking method in the UK and in several other countries — the Chorleywood Breadmaking Process (CBP) (Cauvain & Young, 2006a). Frazier et al. (1975) studied the improvement of mechanical dough development operations to that time in rheological development in the mixer. They indicated that "the Chorleywood Bread Process was the first breadmaking system in which an effective rheological parameter, the work expended on the dough, was used directly as a means of controlling the process".

Table 2.1 shows the main difference between traditional bulk fermentation and CBP. Making bread by traditional methods is a slow process that requires several steps with manual intervention. It also requires long periods of fermentation for the dough to acquire its structure, and it may take several hours to achieve or reach the required dough characteristics. Economically, this is not suitable for high production bakeries because time and effort are essential factors in high production capacity (Tucker, 2019).

Since bread is an essential component of the diet, loaves must be produced at rates of several thousand every hour in many large bakeries. It is challenging to meet the bread needs of a growing population without a fast and efficient breadmaking process like CBP. The central point of difference between CBP and traditional bread making is in one aspect of the process as the mixer operates at a much higher shearing rate (Tucker, 2019).

The speed of energy supply to the dough is very high, which leads to the development of the dough and its desired properties in a few minutes. The endpoint of the mixing is determined by the amount of energy delivered to the dough, and it is not the mixing time that determines the end of the mixing. Mixing under high shear is what characterizes the CBP process. The essential ingredients in bread making are the same in all processes of making flour bread, water, yeast and salt. However, in the CBP process, two different ingredients are introduced, and they are a fast-acting oxidizing agent (vitamin C / ascorbic acid). Also, a small percentage of solid fats or emulsifier addition is required due to the challenge of rapid changes occurring in the dough (Frazier et al.,1975; Cauvain & Young, 2006a; Tucker, 2019).

Table 2.1 Key differences between traditional bulk fermentation and CBP (Tucker, 2019)

Traditional bread making	Chorleywood Bread Process
Gentle dough mixing, with long fermentation times to further develop the dough (mixing/ fermentation takes 4-10 hours)	Vigorous dough mixing to fully develop the dough, with short proving time (mixing/ proving takes 50-60 minutes)
Hard fat not essential, although beneficial	Hard fat essential, or oil plus an emulsifier
Oxidising agent not essential, although beneficial	Fast acting oxidising agent (Vitamin C / ascorbic acid) essential
Standard yeast level	Extra yeast to reduce proving times
Water level estimated from farinograph water absorption values	Extra water to achieve desirable dough consistency after mixing
Atmospheric pressure	Use of Vacuum during mixing to control the gas bubble number and size

All chemical, microbiological and physical processes at the beginning of the mixing process include mixing and moistening flour ingredients, yeast metabolism, enzymatic reactions, trapping small gas bubbles in the dough, and developing gluten matrices. In CBP, the dough does not need time; the mixing element is responsible for connecting the dough with a suitable structure and biology for further processing. Additional water required while mixing the CBP because the dough does not require a long time after mixing when it becomes soft. To obtain a high quality bread, the endpoint of mixing must be optimized and controlled. The dough extracted from CBP should be at its best. To determine the endpoint in most spiral and stirred mixers, mixing is used for a specific time, as is the case in artisanal and intermediate bakeries (Tucker, 2019).

In the case of high-density mixers such as that used in CBP, mixes with constant energy inputs per kilogram of dough. Give this a more consistent endpoint than mixing with time. The mixing capacities of the types of bread in the United Kingdom differ among themselves. The mixing capacities are constant for UK standard bread flour of about 11 W

/ kg of dough, based on work at the British Bread Industries Research Association at Chorleywood (now Campden BRI). The mixing time in a typical mixing is 3 minutes in a high shear mixer, and it may range from two to four minutes depending on the strength of the flour, and the mixing time in other types of dough mixer is 10-15 minutes. More energy to develop gluten is required in flours that contain high-quality protein, perhaps 12-13 W / kg or more. It causes the dough to heat up due to the friction heat. The ideal dough temperature for the CBP process is 30 ° C (Cauvain & Young, 2006a; Tucker, 2019).

Finally, despite the textural and flavour benefits of the bulk fermentation process, the CBP is generally used in preference. Advantages of the CBP include the addition of more water to achieve the desired dough consistency in the mixer, increases the yield slightly, and cost savings through being able to use lower quality wheat and less space and time needed, a result of the lack of proving. Some 80% of the wheat used for bread is now UK-grown, which compares with 30% before the CBP (Tucker, 2019), saving money through lack of imports and cheaper, lower quality flour (the most substantial ingredient in terms of quantity).

2.2.2 Stages of breadmaking

Mixing, proving and baking are significant stages in the production of raised bread. Moulding could be added as fourth aspect to the breadmaking process, with this being a significant stage in the Chorleywood Breadmaking Process. The action at each of these stages is influenced by rheology, and all stages contribute to the aeration of the bread. Mixing serves to entrain bubbles into the dough, moulding aligns the bubbles and constrains the direction of their growth, the bubbles are inflated by the CO_2 generated during proving by yeast fermentation, then baking transforms the foam structure containing separated bubbles into a sponge of interlinked gas cells, as well as determining the shape of the final baked loaf. Rheology interacts with aeration through mixing, and the aeration and rheology established in the mixer determine the development and coalescence of gas cells throughout the moulding, proving and baking stages.

Mixing: during this part of the breadmaking process all the ingredients – flour, water, yeast, salt, sugar, vegetable fat and minor ingredients such as enzymes and conditioners – are combined in the mixer. Once the mixing begins, the ingredients become a homogeneous dough through shearing actions. In this stage, due to the input of mechanical energy into the dough, some important changes occur to the viscoelastic properties of the dough through the stretching and pulling actions. Dough development also occurs, as well as the development of a gluten network for flour produced from gluten-rich grains. The beginning of the formation of gas bubbles in the bread is attributed to the process of folding of the dough over itself during mixing, and thus the gas is retained between the layers of dough. Mixing is a key stage of breadmaking and the next sections give a detailed explanation of the role of mixing in the aeration and development of the dough and the factors affecting it.

Moulding: This is a minor operation in the CBP and one of several processes that come between mixing and proving. These divide the bulk-mixed dough into smaller pieces and form those pieces to obtain the required appearance and structure of the final loaf. During the moulding process, the dough ball is rolled into a flat extended oval shape, thereafter rolled up to a cylindrical format, sealing the layers together by the application of pressure. As a result of the moulding operation, the bubbles are then forced to grow during proving in an elongated direction along the moulded layers. By this means shallow gas cells are produced in the bread, giving a whiter appearance to the slices, while the elongated shape also helps give a strong crumb (Campbell & Martin, 2012; Cauvain et al., 1999).

Proving: This stage, also known as fermentation, is the third main stage of the breadmaking process. After the dough is mixed for a certain length of time, to achieve a high loaf volume and fine crumb structure the dough is then left for 40 to 60 minutes in a warm and humid environment. The recommended temperature at which yeast is most effective is 35-40°C (Cauvain, 2012) with a reduction in proving times using the higher temperatures. Humidity is also a critical factor during proving; the most suitable relative humidity to prevent the dough surface from drying out is 85%. Proving time is determined based on the required baking properties, with a longer proving time required to obtain bread with a coarser crumb, due to the large degree of coalescence which occurs in expansion during proving time, and a shorter proving time results in a finer crumb (Zghal et al., 1999). During the proving stage, the yeast metabolises the sugar in the dough and produces carbon dioxide as a waste product via an enzymatic reaction; the cells are expanded as the carbon dioxide diffuses into them. This stage is therefore also important in the development of dough, and a detailed explanation of its role in aeration of dough is given in the next sections.

Baking: this stage is the final step in breadmaking, during which the dough, now shaped as required, is exposed to heat. During baking, the dough is transformed into bread and can then be consumed as a result of the action of the heat. The high temperature used in bread-baking causes water to evaporate from the dough, reducing the weight of the product (thus making it challenging to prepare loaves with an accurate final weight). The final bread acquires a dry, stable and golden crust due to the evaporation of the surface of the bread during the baking stage. Furthermore, the final bread is characterized by a pleasant flavour due to Maillard reactions – non-enzymatic reactions that occur when reducing sugars react with proteins, peptides, amino acids or amines in food. The application of heat also gelatinizes the starch and brings about protein coagulation, which change the texture of the product as well as its digestibility. Bread is typically baked at 220-230°C, with the heat transferred to the dough primarily by conduction through the pan and convection from the air, with a small radiative component from the oven walls. At the beginning of the baking stage, as the initial temperature rises up to 55°C, the production of carbon dioxide from yeast increases, which was previously produced in large quantities at the proving stage (Zhang et al., 2007). The expansion of the dough in this stage is the final development which is represented in an increase in cell volume, taking the volume fraction of gas from around 75% at the end of proving to around 85% in the final baked loaf (Campbell & Mougeot, 1999).

2.3 Common ingredients in breadmaking and their effect on dough development

2.3.1 Flour

One of the critical factors that affect the quality of the final bread is the type of cereal used. While in the bread industry it is possible to use a number of different grains, flour produced from wheat is most commonly used, because of its advantage in providing a highly aerated structure in the baked loaf (Bloksma & Bushuk, 1988; Bloksma et al., 1988). Dough made from wheat flour is characterized by unique viscoelastic properties, which in turn help to produce and retain carbon dioxide in the dough without cell rupture. The basis for the formation of these properties is the gluten, which is the major component of the wheat protein network (Schofield, 1994). This gluten is made up of a mixture of insoluble glutenin and gliadin proteins. The breadmaking quality of wheat flour is affected by the quantity of gluten and ratio of glutenin to gliadin, which affect the dough rheology (Cornell, 2012; Xu et al., 2007). The role of glutenin is to confer strength and flexibility to the dough, while gliadin confers extensibility, such that together they give good gas retention during proving and baking.

Due to the high use of oxidizers and the shortening of processing time in CBP, it is possible to use wheat with lower protein content and quality compared with other breadmaking processes (Cauvain & Young, 2006b). For example, European wheat can be used, which contains approximately 3% less protein than the American and Canadian winter wheat.

Quality and quantity of the storage proteins are important characteristics in the manufacture of bakery products. Flour with a high protein content is characterized by its viscous and improved properties and produces bread of a larger and better size (Cauvain & Young, 2006b), which is why it is preferable to the use of wheat with less protein in breadmaking. Flour produced from wheat containing 11% or more protein is called strong flour. This type of flour is characterized by its increased absorption of water, giving less aeration and producing doughs of a lower gas-free dough density (Campbell et al., 2001; Campbell et al., 1993; Chin, 2003; Chiotellis & Campbell, 2003b; Dobraszczyk et al., 2001; Sroan & MacRitchie, 2009). Doughs made from weak flour entrain more air than those made from strong flour (Campbell & Martin, 2012); however, how dough formulation and processing affect the gas volume initially entrained into dough has not been widely studied.

The flour content of the enzymes also has a role in determining the properties of the dough. Amylase is one of the most important flour enzymes. The structure of the dough changes when this enzyme, active in the presence of water, breaks down the starch into individual glucose molecules. During the proving stage, the yeast begins its activity and produces carbon dioxide. This process is needed in order to stimulate the activity of yeast, through enzymatic activity, which in turn works to break down starch into sugars that the yeast can metabolise. The degree of enzyme activity in the flour therefore is an important factor in determining product quality. Increasing the enzymatic activity too much overly increases sugars and then reduces the starch content and this produces a weak structure in the final bread, as it reduces the effectiveness of carbon dioxide production and hence gives low volume bread (Wilde, 2012).

Lipids also affect flour properties and baking characteristics. Because of the oxidative susceptibility of lipids, the shelf life of a flour decreases as the amount of lipids increases. The fat content of flour ranges between 1-1.5%, and the type of fats varies with different flours (Wilde, 2012). The polarity and saturation of these surface-active components vary. The dough rheology is not affected by the quantity of lipids present (Sroan & MacRitchie, 2009), but rather the effect is only on the volume and crumb structure (MacRitchie & Gras, 1973; Sroan & MacRitchie, 2009), through the destabilization of the liquid lamellae around the gas cells. In addition to the dough rheology factor, one of the most important other factors affecting the degree of dough expansion is stability of the liquid lamellae and that is through controlling disproportionation and coalescence (Sroan & MacRitchie, 2009).

2.3.2 Water

Water is a component of preparing bread, used to bind all dry ingredients together to form the dough. In order to ensure that the components are properly connected and dispersed optimally, the appropriate amount of water must be added, depending on the flour type, due to the difference in optimal water content for breadmaking from one flour to the next. This amount of water can be determined using a Farinograph or Mixolab, and is typically around 60% of the flour weight. Factors that affect the water absorption of the flour include the protein content, the quantity of damaged starch present, moisture, bran content and arabinoxylans (Cauvain & Young, 2006b). Räsänen et al. (1997) found that reducing the optimal percentage of water by 2% gives unsatisfactory results in the final product, as using water less than the optimal amount reduces carbon dioxide retention and thus reduces the volume of the final loaf. Peighambardoust et al. (2010) also note that the retention of carbon dioxide is affected by insufficient water, because of inadequate gluten hydration.

On the other hand, the increase in the amount of water over the optimum limit has its drawbacks on the dough, the result being a more extensive and viscous dough (Spies, 1990). This affects the processing which becomes more difficult as a result.

Beside the absolute amount of water in foods, the water activity also has effects on the food properties. The water activity depends upon the form in which the water exists in the product, which is determined by the ingredient formulation. Water in food exists in three general forms: (1) free, unbound water, (2) free, immobilised water, and (3) chemically bound water (Belitz & Grosch, 2013). Water activity is reflected in the competition for the water in dough between the starch, protein and arabinoxylans, and the movement of water from the other components to starch during gelatinization, which nevertheless remains incomplete due to the limited water availability.

2.3.3 Yeast

Yeast has been used in making bread for 6000 years (Jacob, 1944), although it was only recognised as a microorganism since the 19th century. Nowadays it is available in compressed, dried, creamed and liquid forms. Yeast is a microorganism; the common yeast species that is used in breadmaking (and also in brewing) is *Saccharomyces cerevisiae*, which has an unlimited number of strains and is used in breadmaking in the form of several thousand varieties (Beudeker et al., 1990). In the bread industry, the best will be chosen from among these strains, or a mixture of them, according to their suitability for the baking process and the product to be manufactured. The differences between these strains are in their tolerance to sugar, their growth rate and their sensitivity to different chemicals. Usually, the performance test is used to find the best yeast for breadmaking, and yeast performance tests assess the production of CO^2 gas during the fermentation or proofing of a dough sample under standardized formulation, temperature and humidity conditions (Paulovich et al.,2010; AACC, 1999). The amount of yeast added varies depending on the manufacturing process. For example, it is added at a level of 2.5% of the weight of flour in CBP, greater than that added in the traditional bread industry, and necessary to ensure adequate carbon dioxide production due to the lack of bulk fermentation in the CBP (Beudeker et al., 1990).

Yeast is primarily responsible for the dough fermentation and obtains its energy through the metabolism of the sugars. The main role of the yeast is the production of carbon dioxide gas by fermentation of glucose. The CO_2 causes the expansion of cells in the dough until the dough becomes highly inflated. If extra sugar is not added in the dough formulation, glucose is completely derived from the flour. The fermentable carbohydrates are 1%, which are ready and available for yeast fermentation. Other dough ingredients may influence the production of carbon dioxide from yeast. The remainder is derived from amylase action on the flour starches (Domingues et al., 1998).

It has been found that adding sugar, alcohol, fat or salt in large quantities reduces the volume of bread (Gujral & Singh, 1999; McGee, 2004; Spaull & Bruce-Gardyne, 2003); if these ingredients are present in large quantities, the amount of yeast should be increased.

2.3.4 Salt

Salt is used in breadmaking in the form of a fine powder, to ensure that it dissolves easily during mixing. It is usually added at the beginning of the mixing, however some bakers prefer to add the salt later, in order to obtain a more expandable dough by providing more opportunity to moisten the protein (Cauvain, 2000). Salt has a number of functions in breadmaking which include:

- Its ability to tighten the gluten network (Belitz et al., 2004). It is reported that salt affects the strength of the gluten network through shielding charges on the proteins, resulting in increased protein-protein interactions which work to make the gluten network stronger (Beck et al., 2012; He et al., 1992).

- Increasing the stability of the dough by allowing hydrophobic and hydrophilic interactions to occur between gluten molecules (Belitz & Grosch, 2013).

- Enhancing the flavour of the bread (Davidson, 2006).

- Reducing the activity of protein-degrading enzymes that damage gluten (Davidson, 2006).

- An ideal salt concentration having a good influence on fermentation tolerance, poring, increases volume of final bread, form, crust and chewing properties of pastries, (Cauvain, 2000; McGee, 2004; Yovchev et al., 2017).

However, the previously all mentioned properties can be decreased, and the activity of yeast also degraded, with the addition of too much salt.

2.3.5 Fat

Fat is added as an ingredient in dough formulation in different proportions according to the type of product to be manufactured. Usually, the amount of added fat is in quantities of up to 5% of the flour weight, but it is recommended to increase the amount for dough formulations based on whole wheat flour (Cauvain & Young, 2007).

On an industrial level, vegetable fat is used in preference to animal fat, which allows vegetarians to consume bread. Triacylglycerols are the primary component of vegetable fats, and their composition and quantity are responsible for the physical properties of the fat. Fats have many benefits for breadmaking:

1. Fat interacts with starch granules and postpones moisture release, which results in delayed staling (Anonymous, 2012c).
2. Fat lubricates the passage of the dough through the equipment (Indrani & Rao, 2002; Anonymous, 2012c).
3. Fat improves the outer surface of the crumbs by increasing the reflection of light, due to the increase the gas–liquid interface of bubbles in the final bread (Brooker, 1996).
4. The solid fat crystals that are formed in the dough around cells augment the bubble stabilizing properties of the gluten network and functional ingredients, such as emulsifiers, and the transport of the interstitial material to the surface of the cell during baking, resulting in greater expansion of the cells without rupture and fusion, and in the end the production of bread of high quality in terms of size and fine crumb structure (Cauvain & Young, 2006b; Li et al., 2004; McGee, 2004).

Many authors recommend that 5% of fat should be solid at proving temperature, to ensure the last two benefits listed above (Brooker, 1996; Dobraszczyk et al., 2001; Gan et al., 1995). Brooker (1996) found that fat crystal melting may occur during proving if lower melting-point fats are used, which reduces the availability for adsorption to cells.

2.3.6 Sugar

In the industry of breadmaking, sucrose is the most commonly used sugar and is sourced from sugar beet or sugar cane. Its chemical composition is two monosaccharides α-D-glucose and α-D-fructose as in Figure 2.2 (Belitz et al., 2004).

Addition of sugar may be in either the crystalline or liquid form. If the sugar added is solid, some or all of the sugar dissolves in the water during mixing. For example, at 25°C, 65 g of sucrose dissolves in 100 g water, and the solubility increases at higher temperatures (Belitz et al., 2004). Although sugar is not used by many bakers because they believe it to be non-essential in bread, sugar can have important functions in the different steps of baking processes. Its presence can be beneficial for improving the quality of bread; it is used for sweetening and helps to mask bitter or sour flavours, giving an attractive brown colour, and provides volume and texture to pastries, increases the gelatinization temperature of starch and represents the main food resource of yeast (McGee, 2004). Moreover, adding the sugar by 1-2% of flour weight helps to accelerate carbon dioxide production by yeast.

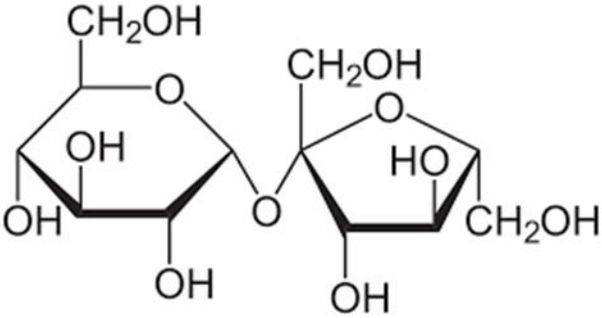


Figure 2.2 The dissacharide structure of sucrose.

As discussed above, addition of a sugar source can be advantageous, however, conversely, the use of too high a sugar quantity has a negative effect on the quality of final product. Adding sugar at levels of more than 10% of flour weight weakens the gluten network by competing with the gluten for the available water (McGee, 2004). The sucrose delays or inhibits glutein cross-linking in sugar-snap cookie dough (Pareyt et al., 2009; Trinh et al., 2015).

2.4 Aeration and development of dough during breadmaking stages

Aeration of foods is a common process, mainly because of its textural benefits (Campbell & Mougeot, 1999), as well as the financial return from selling the air to consumers in exchange for money. In addition to bread, many other foods are aerated to increase their sensory quality, such as ice cream, chocolate and soufflés. There are many methods of aeration that apply to foods, depending on the type of product. Mixing and fermentation processes are the methods employed for bread dough aeration.

The properties of bread, in terms of its appeal and palatability, are dominated by the gas cells that make up 80% of the volume of the final loaf. Therefore, the process of dough aeration during each stage of breadmaking is significant to ensure that the required properties are achieved in the final product. Crumb structure is affected by the space the cells occupy and their influence on the surrounding matrix around them (Cauvain et al., 1999). Gas retention and release operations in the dough are implemented through the different stages of breadmaking. Retention of gas produced by yeast depends on the stability of cells. The following sections investigate how the stages of breadmaking (mixing, proving and baking) affect the dough aeration, and it will be evident that the large focus of the explanation it was on the mixing stage due to the biggest role of this stage in producing gases.

2.4.1 Effects of mixing on the development of bread dough

Gas cells are responsible for forming the structure and properties of the final bread, and the majority of these cells are formed during the mixing stage and are affected by subsequent treatment in terms of their manipulation and retention. The first mechanism for forming bubbles during mixing is the dough layers folding on themselves and forming pockets of gas with diameters on the micrometre scale. These small gaseous bubbles expand by the carbon dioxide gas produced from the yeast during the proving stage later. However, van Vliet (1999) found some cells will not expand because most cells incorporated during mixing are not visible in the final bread, as they do not grow and are physically unstable. Moreover, it suggested that in the baking stage, gas cells with a diameter of less than 100 µm in the aqueous phase do not grow; in other words, the cells must reach a critical size for expansion (Shimiya & Nakamura, 1997).

Mixing is the critical stage through which bakers can exert most control over the gas cells in the final loaf of bread. It is possible to manipulate or change some different parameters in order to improve the distribution of gas cells to obtain a high-quality product. The parameters are classified into two groups; one of them being the dough components as previously described in section 2.3 and the other parameter relates to processing. The processing factors, and their effects on the aeration and development of dough during the mixing, are described in the following sections.

2.4.1.1 *The presence of gases*

Several researchers along the years have mixed dough in different headspace gases in order to understand aeration behaviour. Gases commonly used in filling the mixer headspace are oxygen, nitrogen, carbon dioxide, and a mixture of these gases in the form of air and in other proportions. Dough mixed under high vacuum gave few nucleation sites for carbon dioxide produced by yeast to diffuse into, and resulted in a loaf of low size and weak structure (Baker & Mize, 1937); this was the seminal work that demonstrated the importance of aeration during mixing to create nuclei for CO_2 diffusion. Similar results were shown for cake batters by Dunn and White (1939), and Brijwani et al. (2008) confirmed that biscuit doughs similarly need to be aerated during mixing in order to give an acceptable biscuit structure.

Marston (1986) showed that bread can be developed more effectively by excluding oxygen during the initial period of mixing process, compared with mixing in air throughout. Availability of an oxygen-enriched atmosphere for the second half of the mixing increased the benefit. His results illustrated that there are several potential approaches for decreasing dependence on other additives by manipulating the atmosphere in which the dough is exposed during the entirety of the mixing process.

In the use of CBP in the UK breadmaking industry, oxygen is essential to gluten oxidation through the addition of ascorbic acid for dough development, helping the dough expand without rupture (Baker & Mize, 1941), as well as being rapidly removed from the bubbles through metabolism of yeast. Oxygen also improves the crumb structure and bread volume.

Final bread volume can be increased by mixing different ratios of oxygen and nitrogen, up to a concentration of 60% oxygen (Cauvain & Young, 2006b), although this is not commercially applied.

However, mixing in an atmosphere of pure oxygen also has a harmful effect on the structure and quality of final bread, resulting in a coarse bread similar to that of dough bread mixed in a vacuum (Chamberlain & Collins, 1979). This is because the oxygen is removed, leaving no nuclei for subsequent carbon dioxide diffusion during proving.

The bubbles are formed from the nitrogen gas in the air, and this nitrogen is an essential gas during dough mixing. However, Baker and Mize (1937) found that the dough mixed under an atmosphere of pure nitrogen was soft and sticky and difficult to handle, and resulted in dense bread when baked; findings from Chin (2003) agree with this. This is due to the absence of oxygen which is needed to develop the gluten structure.

2.4.1.2 *The pressure used during mixing*

There are three important factors that have a bearing on dough aeration during the mixing operation: the content of the gas in the dough; the rate of turnover of gas during the mixing process (i.e. the rates of entrainment and disentrainment of gas, the balance of which determines the gas content); and the bubble size distribution (Campbell & Martin, 2012). In doughs mixed under air or nitrogen, their content of gas is proportional to the pressure in the mixer headspace and depends on factors such as the flour strength and the mixer design and operation. Moreover, the number and volume of cells in the dough during mixing are affected by the pressure in the mixer. The quantity of gas in the dough is increased by increasing the pressure in the mixer headspace (Campbell & Martin, 2012) , while mixing at lower pressures gives fewer bubbles in the dough. This leads to less surface area for carbon dioxide diffusion during proving, which causes a greater loss of carbon dioxide to the atmosphere (Campbell et al., 1998; Shah et al., 1998) and a denser final bread with a coarser crumb (Chin et al., 2005; Martin et al., 2008).

Gas contents of 5–10% are typical for doughs mixed at atmospheric pressure. Figure 2.3 illustrates how mixing dough under high pressure creates a more open loaf structure. Increasing the mixing pressure gives a more open breadcrumb grain. Applying partial vacuum tends to decrease the average gas cell size. However, it may reduce or increase the volume of the final baked loaf depending on the timing of the vacuum application.

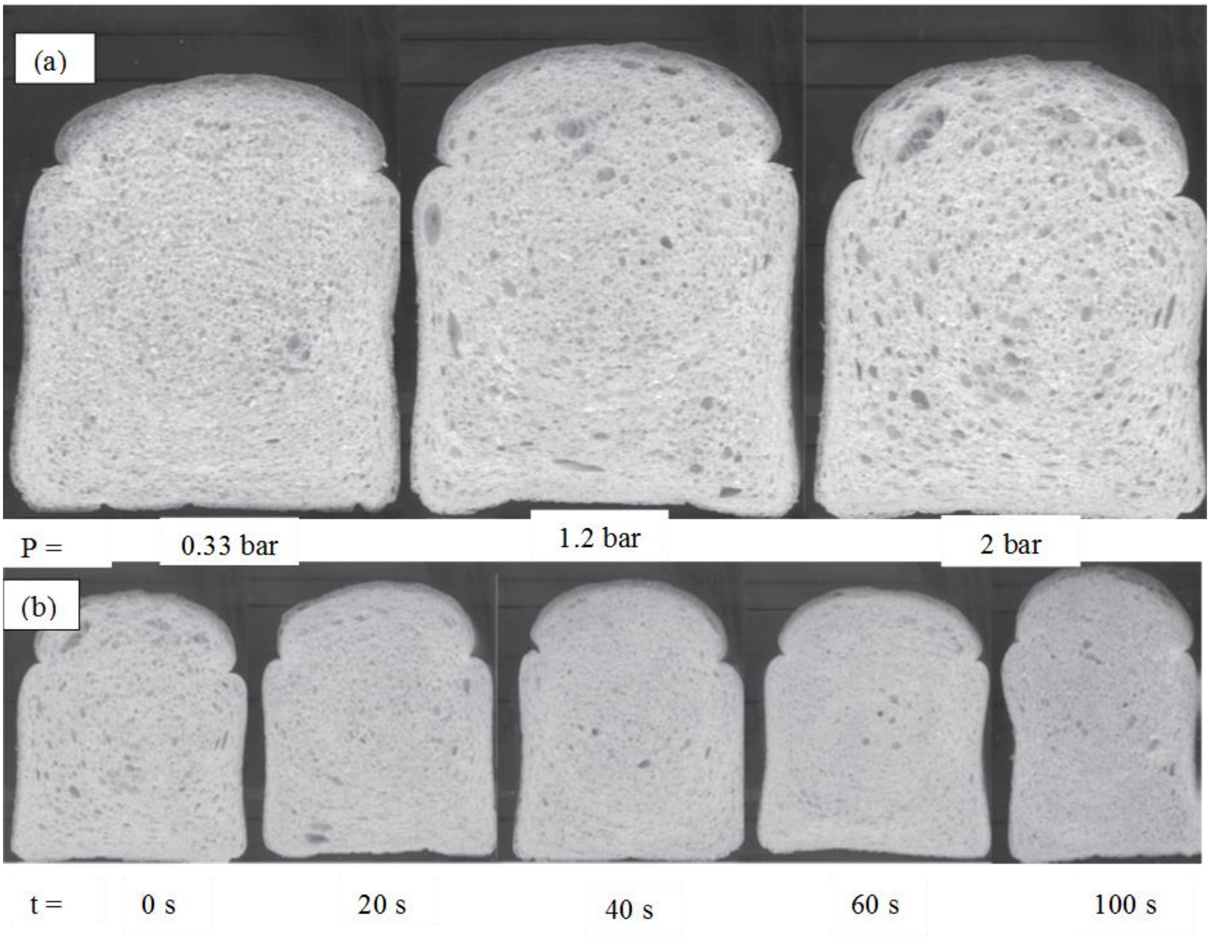


Figure 2.3 Effects of pressure-vacuum mixing on loaf volumes and crumb structures. Top (a): Effect of mixing pressure on loaf volume and crumb structure. Middle (b): Effect of mixing initially at 2 bara pressure, then applying partial vacuum (0.5 bara) at different times before the end of mixing. Source: Campbell and Martin (2012).

In addition, the mixing pressure also has an effect on the time to peak dough development and on the dough consistency. Chin and Campbell (2005a) found that mixing time and work input to peak dough development were reduced by mixing at higher pressures, due to oxygen availability being increased.

Campbell et al. (1998) showed that the range of bubble sizes starts from less than 30 µm to several millimetres in diameter; the size is around 100 µm on average, with about 30–100 bubbles per mm^3. They found that the bubble number per unit volume is changed by mixing at various pressures, however the effect of pressure on the size distribution was relatively weak. The average bubble sizes are small when using high-speed mixing, as practised in the CBP, compared to using slower-speed mixing (Cauvain & Young, 2006b).

Recently, Koksel (2012) determined the dough's bubble size distributions (BSD) and its development using ultrasound and X-ray microtomography in unyeasted doughs. At 30 min after mixing (to allow the dough to relax), the median radius of the lognormal BSD was 6.5 µm. Koksel (2012) also discovered large numbers of very small bubbles using X-rays from a synchrotron source and it was apparent that lognormality did not describe the BSDs.

2.4.1.3 *Development of dough*

Dough development is the one of the primary purposes of mixing. The two critical factors that affect the dough development, mixing speed and time, determine the work input into the dough. The mixing speed is a more important factor than the mixing time. Kilborn and Tipples (1974) found the mixing time cannot be increased to compensate for the mixing speed, although the opposite can be done. They also found, regardless of the input level of work, that every flour has a critical speed below which dough development cannot be achieved.

The aeration of the dough is increased very efficiently by increasing mixing speed for a set mixing time, resulting in high quality bread with greater volume (Campbell & Herrero-Sanchez, 2001; Campbell et al., 1998; Chin, 2003; Chin & Campbell, 2005b).

Kilborn and Tipples (1972) and Cauvain (2000) found that the after the dough reached peak development and is then subjected to further mixing at a low speed, this resulted in underdeveloped dough. This is known as a “unmixing” phenomenon. This is the result of the pressure resulting from mixing placing stress on gluten molecules, causing them to break apart (Spaull & Bruce-Gardyne, 2003). This result is a moist dough of high viscosity that is difficult to handle (Hoseney, 1985) and its ability to expand and its flexibility is reduced (Calderón-Domínguez et al., 2008).

2.4.1.4 *Mixer scale*

Mixer scale affects the degree of dough aeration in high-speed mechanical dough development mixers (Campbell & Shah, 1999). It is found that when changing the mixing scale while maintaining the rest of the parameters, the dough has the same number of cells with a varying gas volume (Martin et al., 2004).

On scale-up of the original mixer used in the CBP, it was found that aeration of the dough increased, leading to unacceptable bread quality. Thus, although dough aeration during mixing is essential to provide nucleation sites for CO_2 inflation, too many bubbles in the dough lead to a poor structure. This problem was rectified by mixing under a partial vacuum (with reference to the work of Baker and Mize, 1941), such that mixing at less than atmospheric pressure in order to control dough aeration became a distinguishing feature of the CBP, hence leading to much research in the UK on bread dough aeration (Campbell & Martin, 2012; Cauvain & Young, 2006a).

2.4.1.5 *Mixer Design*

One of the factors that relate to dough aeration and dough rheology during the mixing process is mixer design and operation. Kilborn and Tipples (1974) conclude that “much scope may exist for modifications to mixer design to allow for development of doughs in a more efficient manner.” The shape of the mixer bowl, the blade geometry, the mixing speed and the rheology of the dough should be taken into consideration during the mixing action. In doughs mixed under air or nitrogen, their content of gas is proportional to the pressure in the mixer headspace and depends on factors such as the flour strength and the mixer design and operation (Campbell & Martin, 2012). Peighambardoust et al. (2010) found that the density of the dough is affected by the type of mixing action used. Campbell et al. (1991) found similar effects on the bubble size distribution in the dough.

Determining the distribution of bubble sizes in doughs is difficult, and the influences of only a few factors have been studied to date, related primarily to dough formulation and the design and operation of the mixer. The equilibrium between the rates of air entrainment and distrainment during the mixing process and bubble break-up influence the air content and bubble size distribution. The turnover of air affects the presence of oxygen during mixing. Chamberlain (1979) (cited in Campbell and Martin, 2012) reported a “suspicion that the availability of oxygen varies from one mixer to another” and that in studies with oxygen-enriched headspace atmospheres in the mixer, the oxygen “clearly was not gaining access to the dough in sufficient quantities”.

2.4.2 Effects of moulding on the development of bread dough

Moulding is one of several operations that come between mixing and proving to divide the bulk-mixed dough into smaller pieces and form those pieces to obtain the required final loaf appearance and structure. During moulding, the dough ball is rolled into a flat extended oval, thereafter, rolled up to a cylindrical format, sealing the layers together by application of pressure. As a result of the moulding operation, the bubbles are subsequently forced to grow during proving in an elongated shape along the moulded layers. By this means shallow gas cells are produced in the bread, giving a whiter appearance to the slices, while the elongated shape also grants a strong crumb (Campbell & Martin, 2012; Cauvain et al., 1999).

Moulding has a critical effect on bread texture but is not clearly understood (Cauvain et al., 1999; Leong & Campbell, 2008). The moulding operation of dough is another interaction that occurs between aeration and rheology. In addition to affecting the subsequent development and orientation of bubbles during proving, the dough is degassed to some extent and the remaining gas is redistributed inside the dough slices by moulding (Leong & Campbell, 2008; Whitworth & Alava, 1999).

With the development of mechanical dough operations such as the CBP, moulding is implemented before perceptible yeast activity has occurred. This explains why the moulding does not substantially modify aerated dough structure from that delivered by the mixer, as it would be in a traditional bulk leavening operation. This is demonstrated by the observation that mixing at various pressures impacts baked loaf texture despite the moulding process being implemented after mixing (Campbell et al., 1998). There are three reasons for differences compared with Bulk Fermentation processes: the gas content directly before moulding is reduced; the dough rheology is less relaxed; and there is a difference in gas composition, being less dominated by highly soluble carbon dioxide and more by relatively insoluble nitrogen. The gas distribution and effects on subsequent bubble orientation are changed by moulding, however, this does not remove the link between the aerated structure formed in the mixer and the development of the bubbles through proving (Campbell & Martin, 2012).

It has long been known in bread manufacturing that both the gluten network and the gas bubbles formed in the dough after the process of mixing and proving should not be subjected to more mechanical pressing. As is the case when manufacturing French and Italian bread (baguette and ciabatta), which also needs to be increased by adding water to help create a distinct, open and random cell structure (Cauvain, 2015).

The creation of voids and holes in the final baked loaf is attributed to dough processing, especially moulding. These holes are due to pockets of gas trapped inside the dough at different stages. There are several opportunities for the occlusion of large gas pockets during dough processing, but they depend mainly on rolling and changing the shape of the dough in the final moulder (Cauvain, 2015). Computer tomography (TC) was used to show that while voids may be clogged in the dough pieces after the divider stage, or they will survive the sheeting rolls or if they did, then they should be had smaller than the dough gap (Cauvain 1996, 2002, 2015). The results showed that the reason for the formation of many large holes was during the curling process, because they are mostly located towards the ends of the piece of dough.

The other holes that form in the dough later are formed during the proving and the final baking stages. The reason for the formation of these holes is the damage to the thin bubble structure in the dough, and the cause may also be due to the high pressures on the dough when the dough piece passes under the final moulding board. The use of high pressures is often used to "mould out" from trapped gas pockets but often creates the same problem. Gas bubbles will expand more readily and coalesce when they touch due to the mechanical breakdown of the gluten network between them. Areas of relatively low pressure are formed due to the increase in the size of the bubbles, and the carbon dioxide from the yeast fermentation diffuses preferentially (Cauvain,1996, 2002 & 2015).

Consequently, the larger gas bubbles only expand, whereas the smaller ones remain relatively unexpanded. The hole will remain in the final product if the expansion of the dough is sufficient. Expansion occurs only during final moulding; the rheological properties are critical in reducing unwanted hole formation with "stiff" doughs being more susceptible to damage (Cauvain & Young, 2008).

Cauvain and Young (2006b) explained how the bread structure, which processed using four piecing varied in a systematic a long, the length of the final baked loaf (i.e. from piece to piece). They suggested that “the areas where the of such structures is a direct consequence of the efficiency of the moulding, cutting and pouncing operations associated with four-piecing”.

2.4.3 Effects of proving on the development of the bread dough

Like mixing, proving is a significant stage in breadmaking and its defining process. Figure 2.4 shows the bubbles formation during the breadmaking stages. The distribution of bubble sizes, which are created in the mixer, are joined with each other by proving to comprise the distribution of gas cells visible in the final bread, by the dynamics of CO_2 generated by yeast fermentation and its mass transfer into bubbles. This link underpins the motivation to understand dough aeration during mixing. The unique viscoelastic rheology of wheat flour doughs, arising from the unique gluten proteins of wheat, allows this expansion of bubbles and retention of gas, such that highly leavened bread can be only made from wheat (He & Hoseney, 1991).

The accepted understanding is that the viscoelastic nature of developed dough protein gives the dough the ability to retain gas during proving (Hlynka, 1970; Noel & Brownsey, 1990). An optimally developed protein network is elastic enough to retain gas produced by yeast metabolism while viscous enough to flow to allow the dough to expand. Modelling of bubble development during proving helps to clarify the relationship between aeration of the dough through mixing and the aerated structure of the baked loaf. Some models of different applicability and complexity have been advanced (Chiotellis & Campbell, 2003a), but there are still problems related to experimental validation.

Cell coalescence is the main instability mechanism that occurs at the end of the proving stage and during the early stages of baking (Van Vliet, 1999) due to the expansion of the dough caused by increased carbon dioxide production by yeast and the formation of steam during the proving stage. This phenomenon does not occur during mixing due to the small size of the cells. However, the available CO_2 gas, which faces a complex competition among aeration during the operation of mixing and the final bread structure, depends on the coalescence of bubbles in the final phases of proving and the first period of baking. Cell coalescence occurs as a result of the rupture of the dough layer between cells and then fusion of them. This is due to the development of weak spots that are caused by local thinning (Van Vliet, 1999; Van Vliet et al., 1992). Too much coalescence causes a large loss of gas, resulting in too much loss in volume of final loaf.

The surface rheology of bubbles has been identified as an important factor in addition to bulk gluten rheology. It has been proposed, in the liquid film hypothesis, that discontinuities are developed in the weak gluten film between bubbles at the end of proving; the existence of a thin liquid film containing water-soluble surface-active ingredients, however, retards coalescence (MacRitchie, 1976). As well as good quality gluten, the contribution of surface-active materials is also required for good breadmaking performance. This contribution gives a small additional bubble stabilization that distinguishes a good breadmaking flour from a poorer one. Gan et al. (1995) reviewed the evidence for the liquid film proposition, and new studies have provided extra evidence to support the hypothesis (Mills et al., 2003; Sroan & MacRitchie, 2009). Thus, both bulk and surface rheological impacts contribute to bubble stability and the quality of the aerated structure of bread.

The rupture of the thin dough causes coalescence between gas bubbles films, which results in loss of gas and an irregular bread structure (Kokelaar & Prins, 1995). As noted above, surface-active materials promote the stabilization of the thin film. Nevertheless, there is a lack of direct studies on bubble coalescence in expanded bread doughs, as these events are extremely difficult to observe.

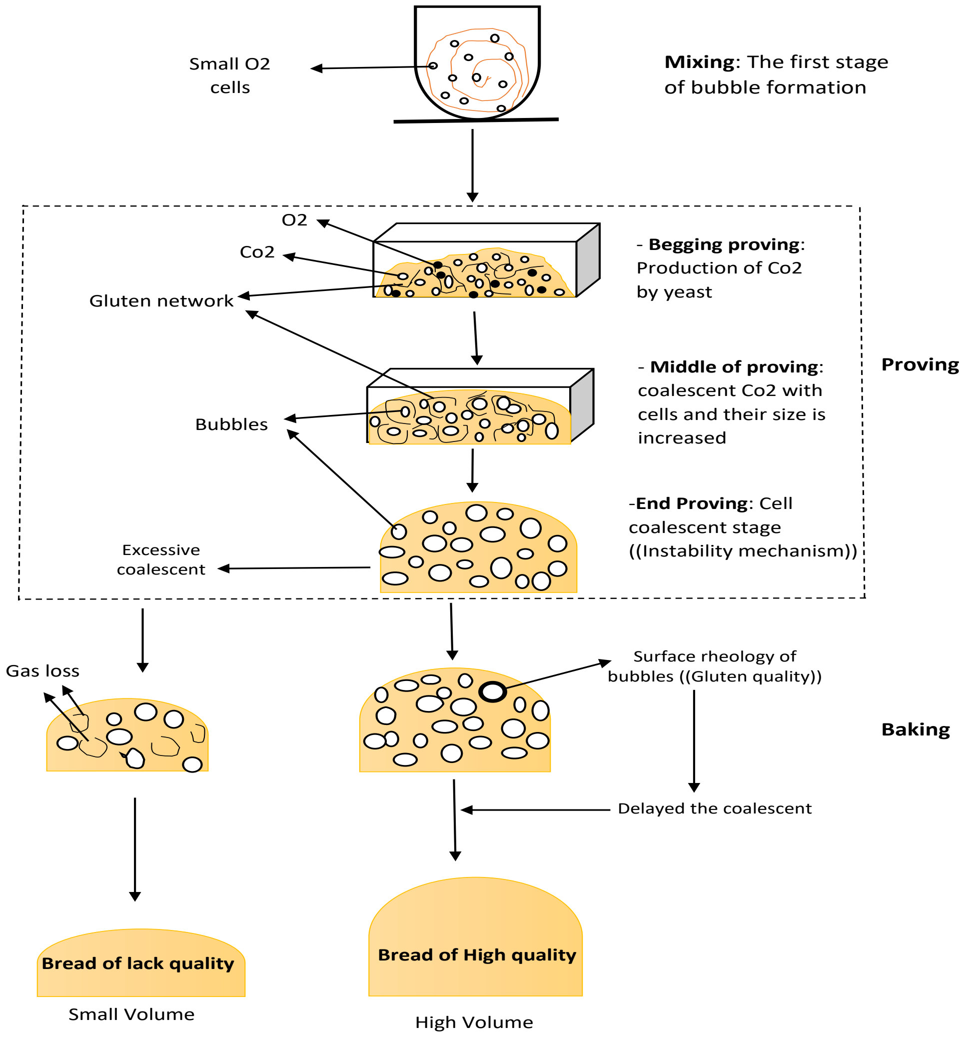


Figure 2.4 Foam formation and stabilization in dough systems.

2.4.4 Effects of baking on the development of bread dough

The baking process is an advanced operation that requires the facility to include the food in the dry heat ambience of an oven. Many artisan and commercial bakers stress that the most crucial component for the manufacture of truly good bread quality is the oven, and that the most critical stage in breadmaking is the baking process (Calvel et al., 2001; Collister & Blake, 2000; Pyler, 1973). The complicated chain of chemical, biochemical and physical transformations, the spatial arranging and sequencing of which are critical, all occur because of baking.

Baking causes the dough structure to set and bubbles to coalesce and rupture to form an interconnected network of gas cells, to give the familiar aerated bread texture. Increasing yeast activity at high temperatures increases gas production, but the gas production stops at around 55°C at which point the yeast dies and its activity stops. This contribution to expansion of the dough is termed oven rise (Hlynka, 1970).

The contribution of the baking operation to aeration of bread is based on the key physical phenomena that accompany transfer of heat from the outside to the inside of the bread, that as temperature increases, ethanol, carbon dioxide and other components that are dissolved in the aqueous phase of the dough come out of solution into the bubbles. Moreover, water evaporates and expands the bubbles. Combining these phenomena with the thermal expansion of the gases gives growth of the dough in the oven, referred to as "oven spring". Between them, "oven rise" (continued production of carbon dioxide by yeast during the early stages of baking, before the temperature gets too high and kills the yeast) and "oven spring” bring the quantity of gas in the final bread to about 75–85%, dependent on the bread type (Campbell & Martin, 2012) .

The pressure inside the baking dough is also increased by the crust that is created on the outside of the bread. Hayman et al. (1998) found that bubble coalescence and the damage of fine structure are encouraged by this crust. This coalescence occurs when the temperature decreases among bubbles detached by still viscous dough, which causes a reduction in the number of bubbles and thickening of the bubble structure but does not result in a loss of gas. Surface-active factors in the liquid film contribute to firmness against coalescence and help to retain the fine gas cell structure

The leavened dough structure is a dispersion of detached bubbles in a continuous protein template; the viscoelasticity helps the bubbles to expand and maintain gas (Bloksma, 1990b; MacRitchie, 1976). The matrix ruptures during baking, resulting in a continuous gas stage and thus the rapid loss of gas (Bloksma, 1990a, 1990b).

2.5 Methods of studying bread aeration and dough rheology

Baker and Mize (1937, 1941) were pioneers in bread aeration work and the first to demonstrate that the origin of the aerated structure of bread is the aeration of the dough during mixing; they showed that the yeast cell is unable to create new bubbles from nothing, but can only inflate existing bubbles that have been entrained during mixing. The most important conclusions from this pioneering work regarding aeration of bread dough arose from the use of two key measurement tools: the measurement of dough densities, and the examination of final baked loaves. Subsequent studies have relied on applying these techniques widely. The gas phase behaviour was also investigated during the baking process in an electrical resistance oven (Baker & Mize, 1939). Campbell and Martin (2012) list a range of other techniques that have been used to study aeration of dough:

1. Vacuum expansion of dough (Bell et al., 1981).
2. Measurement of CO2 production and retention (Chiotellis & Campbell, 2003b).
3. Evaluation of volume variations and gas release during proving and baking (Mondal & Datta, 2008).
4. Light microscopy and scanning electron microscopy (Aranyi & Hawrylewicz, 1968).
5. Measurement of bubble size distributions in doughs (Bellido et al., 2006).
6. Bubble inflation rheometry (Reuge et al., 2001).
7. Measurement of interfacial characteristics of dough components (Kokelaar & Prins, 1995).
8. Evaluation of ultrasound propagation (Leroy et al., 2008).
9. Photographic analysis of the crumb structure of baked loaves (Lassoued et al., 2007).
10. X-ray and magnetic resonance imaging (MRI) tomography of proving and baking doughs (Babin et al., 2006).
11. Texture analysis of bread (Gonzales-Barron & Butler, 2008).
12. Sensory analysis of bread (Mann et al, 2015; Gambaro et al, 2007; Heenan et al, 2008; Heini et al, 2016)

Recently, ultrasound and tomography, which are modern techniques, have emerged as powerful tools for comprehending bubble behaviour during breadmaking (Campbell & Martin, 2012). These techniques are used to exploit the large difference in the density of air bubbles and the dough matrix to permit a quantification of the bubbles in the dough. Tomography is used for investigating the dough's development during proving and baking (Whitworth, 2008; Whitworth & Alava, 2002, 2004). The dynamic nature of bubbles in the dough is one of the difficulties that confounds efforts to obtain high-contrast images. For, instance, Bellido et al. (2006) waited 90 minutes after mixing before trying to estimate bubble size distributions in the dough using a bench-top micro-tomograph. Babin et al. (2006, 2008) exploited the high-density X-rays from a synchrotron source with fast acquisition times for each radiograph to conduct high-resolution studies of the growth and coalescence of gas bubbles during proving and baking.

2.6 Summary

Breadmaking involves three major operations; mixing, proving and baking, in which aeration and rheology interact to link the bubble and gluten structures created during mixing to the final baked loaf quality. In modern breadmaking processes, intense high-speed mixing imparts work to the dough to develop the gluten structure while aerating the dough. Mixer headspace pressure is manipulated to control the oxidation of the dough and the creation of the bubble size distribution. The bubble size distribution established during mixing evolves during proving and baking to give the desired gas cell structure in the final bread.

In addition to these three operations, other operations such as moulding influence the dough rheology and the growth of the bubbles. Moulding includes a sheeting operation that forces bubbles to grow in orientations aligned with the sheeted dough. However, sheeting can also be used to develop the gluten structure of doughs more efficiently than by high speed mixing. This is difficult to implement in commercial practice, but some bread manufacturers are looking into this technology. It is therefore timely to apply the techniques that have been used to understand aeration and rheology during mixing, proving and baking, in order to begin to understand how the sheeting operation interacts with aeration and rheology, and to ensure that its commercial implementation is optimised for minimum energy usage and maximum bread quality.

The current work focuses on the effects of sheeting on dough development and aeration. The initial studies were performed on white flour doughs, followed by studies that incorporated bran of different particle size into the dough formulations. The next chapter therefore examines in greater detail the current state of knowledge around sheeting of doughs.

Chapter 3. Sheeting and breadmaking

3.1 Introduction

Mechanical dough development using high speed mixers in processes such as the Chorleywood Breadmaking Process transformed the breadmaking industry in the last century. However, high speed mixing is energy intense and expensive. Sheeting offers different mechanical means of dough development, and this process is not new (Kilborn & Tipples, 1974; Chin & Campbell, 2005a). Many years ago, in countries such as Central and South America and Africa, the dough-brake was widely used due to its efficient mechanical development effect, in addition to other beneficial effects (Levine & Drew, 1990). However, in these countries no attempt was made to shorten the long fermentation period or eliminate it by using sheeting more effectively.

The terms sheeting and moulding are used in the same process task performed by both with a minimal difference in how they work, as the sheeting tends to refer to a wide, continuous strip of dough, with the purpose of developing the gluten (in the case of bread doughs) or simply producing a thin layer (in the more common case of biscuit doughs – for which it is necessary to avoid gluten development). Moulding is sheeting of an individual dough piece followed by rolling, for the purpose of orienting the growth of the gas cells during proving and baking. In the sheeting process, the dough piece is forced between single or successive pairs of rollers to decrease its thickness. Within breadmaking, the moulding operation employs sheeting through two or three pairs of rolls prior to rolling up the dough piece to orient the subsequent growth of the bubbles. Biscuit manufacture also employs sheeting to produce a very thin dough sheets (typically 2 mm in thickness) from which biscuits are cut and baked (Brijwani et al., 2008). In both bread and biscuit dough sheeting there is some degassing of the dough during sheeting (Brijwani et al., 2008; Leong & Campbell, 2008).

This chapter reviews previous research and the current state of knowledge about sheeting, leading to the objectives for the current studies.

3.2 Effects of sheeting and moulding on the development of bread dough

Rolling is commonly used for materials in many industries, including polymer processing, metal forming and food production. Some of the studies highlight the sheeting of food products such as dough, cookies and pizza (Levine & Drew, 1990).

It is increasingly recognised that bread texture is significantly affected by the moulding operation within breadmaking; however, this operation has been largely neglected by researchers and the details of its effects are unclear (Leong & Campbell, 2008). In spite of the benefits of moulding, there is also the risk of damaging quality in the baked products through incorrect moulding (Leong & Campbell, 2008). This potential for damage arises due to the severe deformations that the dough experiences within the moulding process and due to the effectiveness of dough sheeting in developing and over-developing (i.e. deteriorating) gluten structure (Feillet et al., 1977; Kilborn & Tipples, 1974; Menjivar, 1990; Moss, 1980; Moss, 1974).

The main objective of moulding is to provide a desired texture and appearance of final baked products, specifically a firm texture with a fine cell structure, although there is ambiguity in understanding the precise mechanisms by which moulding contributes to these characteristics.

Sheeting of dough, as illustrated in Figure 3.1, is a significant processing phase in the production of bakery products such as biscuits, cookies, crackers, pizza, noodles, pastries, bread and some types of pasta (Qi et al., 2008). Doughs are formed appropriately by sheeting for subsequent processing; however, sheeting can also give additional benefits. In breadmaking, sheeting is applied to dough pieces during moulding, as the final step of dough manipulation before proving and baking; for doughs that have undergone bulk fermentation, moulding has a fundamental role in the division of large gas bubbles that are in the dough and helps to generate and distribute bubbles in all parts of the dough piece to ensure bread with a fine and uniform crumb texture (Kulp, 1988). There is a difference between manufacturers in the design of the rollers used in dough sheeters. Some of the systems prefer successive sheeting rollers of fixed but gradually narrowing gaps, whereas others prefer massive cylinder and roller sheeting systems in which the piece of dough is reduced in thickness once between a drum and a non-stick roller. Some manufacturers provide adjustable sheeting pressure. They use compressed air or springs, and they claim that by these the sheeting action can be more responsive to the rheology of the dough passing during the gap. The speed of the rollers and reducing of gap reflect the dough rheology. If there is a narrow gap and the speed of the rollers is too high for the dough rheology, then the place of ‘scrubbing’ will be at either between the roller and the dough piece, or between the internal and external structures in the dough piece. When this occurs, damage results as tear marks on the dough surface. When multiple sheeting sets are united, the relative roller speeds might also be critical

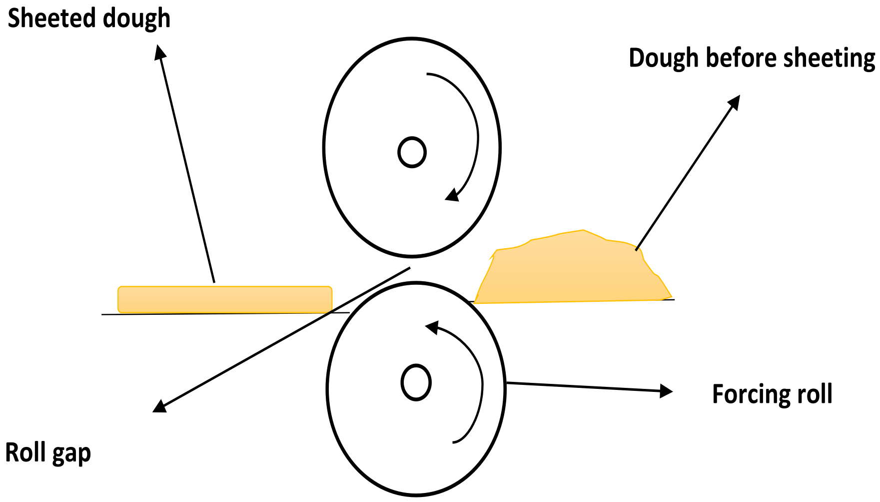


Figure 3.1 Sheeting operation parameters.

The rheological properties of the dough pieces and the gas bubble structures within them are affected by the dough processing steps that follow the mixing stage and precede the entry of the dough pieces to the final proving stage in which are represented in the moulding/ sheeting process. In modern no-time doughs (CBP for example), the gas bubbles structure that is created during mixing will be expanded in the proving step, and then they will be placed in the oven. Some expansion occurs in these bubbles during the moulding process but will be minimal compared to that which occurs in the proving and baking operations (Cauvain, 2002, 2015). To avoid damage of gas bubbles structures in the dough, the interactions between the dough rheology and moulding processes should be optimized. The formation of large holes and streaks of crumbs that are pale or dark in colour are the most common manifestations of damage to the structure of gas bubbles in the dough (Cauvain &Young, 2001).

Despite the lack of studies on sheeting and its effects on the development of dough, there has been some discussion in the literature about this process and its use in bread production. Stenvert et al. (1979) found that a very fine-grained bread is produced by sheeting. To prevent the overworking of the dough by the sheeting rollers, they recommend the importance of using very stable doughs. This conclusion about the importance of controlling work while dough sheeting was also reached by Moss (1980). Expelling excess air and carbon dioxide from dough is the most important of all the sheeting effects on bread doughs (Pyler & Gorton, 1988). Moreover, Matz (1992) suggests that some excess carbon dioxide may be forced into solution by the pressure developed between the rolls. Then, fine bubbles (nucleation sites) are generated by this dissolved gas. Generation of fine bubbles are done when they come out of the solution when the pressure is released.

The focus of some studies on moulding has been on practical guidelines for moulder operation and their effect on the quality of the final product (Pyler, 1952; Marsh, 1998; Zghal et al., 2001); new moulder designs (Pyler, 1952); the extent of the gluten development from sheeting operations (Kilborn and Tipples, 1974; Moss, 1974; Feillet et al., 1977; Moss, 1980; Menjivar, 1990; Levine, 1996a); the effects may be encountered by the bubble structure in the dough from sheeting and moulding operations (Stenvert et al., 1979; Matz, 1992; Pyler, 1998; Cauvain, 1998). Some other studies have focused on the moulding of fluid mechanics during the sheeting of dough (Zghal et al., 2001; Levine, 1991, 1996a,b, 1997, 1998; Levine and Levine, 1997; Levine et al., 2001, 2002).

The studies above have explained that the shape and degree of development or damage of the dough piece have affected by sheeter design and operation and dough characteristics, and that sheeting has the potential to develop gluten structure developed. Studies using X-ray tomography have suggested that "the surfaces of the sheeted dough piece, which subsequently form the joins in the moulded dough piece, are degassed more than the interior, causing a dense spiral in the dough which persists during proving and is evident in the baked loaf" (Whitworth and Alava, 1999). Dough structure is also developed by sheeting. Kilborn and Tipples (1974) found that the dough structure developed when the dough passed 15 times through sheeting rollers was similar to that obtained with a traditional mixer, however, only 10–15% of the energy was required for sheeting compared with mixing to reach the same stage of development. This data was re-examined by Levine and Drew (1990) who found that “the data produced plots of dough viscosity development versus total energy input that look very much like those often reported for the development of doughs by mixing. The curves exhibit an increase of viscosity as work is imparted and ultimately the breakdown of viscosity with the continuing application of work”. Bloksma and Bushuk (1988) found that a sheeting process, which does not require a powerful, high-speed mixer (hand-mixing followed by sheeting development), produced a bread of similar size to the bread produced by the Chorleywood Bread Process. Morgenstern et al. (1999) found that the number of sheeting passes applied to the dough can contribute to modifying the volume and crumb structure of the bread.

Stenvert et al. (1979) noted that there is a clear effect from repeated sheeting on the build-up and breakdown of a protein network structure, and Moss (1980) found that the number of sheeting passes affected the rheology of dough. According to Erlebach (1998), there is an increase in the number of extended bubbles (‘streaking’) in bread made from sheeted dough. These studies focused on the number of sheeting passes rather than on some other conditions of sheeting process such as the geometry of the sheet and rolls, gap setting, speed of rolls and conveyor system and contact between rolls and dough.

The rheology of the dough has a substantial role in defining the processing behaviour and final quality of baked products (Bloksma, 1990b); it is not surprising, therefore, that rheology of dough also affects the dough sheeting operation. These effects include the changes to the inside dough and bubble structure to adverse rupture or sticking of the dough surfaces to the rollers, and to differences in the final product thickness because of dough springback, or recoil, after sheeting.

Patel and Chakrabarti-Bell (2013) studied effects of sheeting on the development of dough prepared from six different kinds of flours. They concluded that the protein content in flours was not an important operator for dough elasticity and that the important role in relaxation times is moisture in doughs. Brijwani et al. (2008) studied aeration of biscuit doughs, and a flour-water system, during the mixing operation and after the sheeting process. The mixing was undertaken at various pressures; they also studied the effects of mixing air and CO_2 within the dough on final dough structure and texture. It was found that using high pressure and/or with CO_2 in the mixer headspace atmosphere gave softer doughs and biscuits, and that the sheeting regime, whether Severe (a few large decreases in roll gap), Standard or Gentle (numerous small reductions in roll gap) affected loss of gas, with Gentle sheeting giving the greatest loss of gas.

Leong and Campbell (2008) similarly investigated that the loss of gas in unyeasted bread doughs as a function of the number of sheeting passes. Degassing was affected by sheeting conditions and the initial gas content. The decrease was not uniform within the sheeted piece of dough, however; the greatest decrease was in the front border and at the sides, and the least in the middle. They also found that as the roll gap decreased, the change in density and hence a change in gas content increased. Dough prepared from strong flour had a higher density change when exposed to sheeting compared to flour prepared from weak flour. The magnitude of change in dough density with sheeting is greater when mixing dough under 2 bara pressure comparing mixing dough under atmospheric pressure. This means that the extent of dough degassing during sheeting increases with an increasing initial gas content of the dough prior to sheeting and depends strongly on the roll gap. Their results also show that decreasing of roll gap decreased the gas content of the sheeted doughs made from both strong and weak flours. This is due to the increased development of pressure resulting from the reduction of the roll gap. The large pressure rise with decreasing roll gaps would cause the gas within the dough to be compressed and removed to a larger extent compared to that at wider roll gaps.

3.3 Measurement of dough development

The purpose of mechanical dough development via high speed mixing is to develop the dough structure so that its ability to retain gas is enhanced. Sheeting offers an alternative approach to dough development that aligns gluten proteins more efficiently, and thus can achieve dough development more efficiently in terms of energy usage and more effectively in terms of bread quality.

In principle, the effects of sheeting on bread quality are best investigated by baking loaves. However, this is expensive in research terms and requires substantial facilities and breadmaking experience and does not give helpful mechanistic insights into how sheeting exerts its effects and how it might be optimised.

The Dynamic Dough Density (DDD) test has been introduced in recent years as a simple but sensitive measure of the ability of doughs to expand during fermentation (Campbell et al., 2008a, 2008b). It is a unique system in our laboratories; no other research group in the world has this facility. The test uses yeasted doughs (hence is closer to reality than tests that use unyeasted doughs) to measure the changing density of the dough as the yeast causes it to inflate. The minimum density indicates the maximum ability of the dough to expand, hence gives a direct measure of dough rheology as it relates to this key measure of dough character. The current project therefore took the opportunity to apply this DDD test to yeasted doughs that have been sheeted to different extents, to see if the rheological development imparted by sheeting can be understood and optimised using this test. The effect of sheeting on aeration was also examined by measuring the static density of unyeasted doughs after sheeting.

3.4 Formulations of research objectives

Sheeting affects bread texture, but compared with mixing, proving and baking, there have been relatively few studies on sheeting and only limited knowledge about the effects of sheeting on the dough behaviour and bread quality. There is current interest in using sheeting commercially for bread dough development, to obtain better bread quality with lower energy input; however, the efficiency of sheeting in developing gluten can lead to the risk of over-development and hence damage to baked loaf quality (Marsh, 1998).

Although bran-rich bread is a source of beneficial fibre for health, some studies found the harmful effect of wheat bran on breadmaking and final loaf quality in terms of the functional and the sensory characteristics of bran. The superior gluten development that can be achieved by sheeting may offer a route to alleviating these negative effects, to produce wholemeal breads of larger volume and greater softness that will be more acceptable to consumers.

The Dynamic Dough Density test offers a convenient and sensitive method to quantify effects of sheeting on dough development. The initial objectives of this research, therefore, were to apply the DDD test to measure the effect of sheeting on dough development. Static dough density tests were also used to measure the effects of sheeting on dough aeration. Subsequent work developed a further measure of dough development based on the recoil or springback of doughs after sheeting, and extended the investigation to include effects of bran on water absorption and effects of sheeting and bran on baked loaf volume and structure.

3.5 Summary

Bread is the world's most important food because of its aerated structure, and wheat the world's most important cereal because wheat flour, uniquely, is able to form a dough capable of retaining fermentation gases to produce the great variety of light, palatable bread types (Campbell, 2008). The ability of wheat flour doughs to retain gas is enhanced by developing the dough to align the gluten proteins. Development can be achieved by high-energy mixing or, more efficiently (but less easily in terms of practical implementation) by sheeting. Dough density allows effects of sheeting (and other dough processing conditions) on aeration to be measured, while the Dynamic Dough Density test is a sensitive method for quantifying dough development in terms of the ability of doughs to retain gas. The objective of the current work was therefore to apply the DDD test and other modern techniques to understand how sheeting develops the aeration and rheology of bread doughs, in order ultimately to enhance the commercial application of sheeting for bread manufacture.

In addition, a study of the effect of bran on the characteristics of the dough during sheeting and its effect on the quality of the final bread is an important aspect of developing the wholemeal bread quality to increase consumer demand because of its health benefits. The next chapter describes how the bran affects the dough properties and the quality of final bread.

Chapter 4. Bran and bread dough

4.1 Introduction

Fibre-rich, wholemeal bread has been encouraged by nutritionists and bread manufacturers in recent years because it is healthier than white bread, yet the majority of consumers prefer the taste and texture of white bread and are more likely to purchase it in preference to brown or wholemeal (Mann et al, 2015; Acevedo et al, 2019; Gambaro et al, 2006; Heenan et al, 2008; Foster et al, 2020). The reason for this is that the presence of fibre (mostly in the form of wheat bran, although other fibre types can be used in bread) damages the development of the gluten and the creation of the aerated structure that gives the high-volume, soft bread that consumers like. The water absorption is also impacted by adding the bran, resulting in a negative effect on the dough properties which are responsible for the quality of final bread.

This chapter reviews the effects of adding bran to flour on the development of the dough and the quality of the bread, and the effect of the bran particles on the water absorption of the flour, and presents reported approaches to overcoming negative effects to produce healthy breads that are also acceptable to consumers.

4.2 Health benefits of dietary fibre

Dietary fibre is found naturally in the form of carbohydrates in all edible plants. Vegetables, grains, cereals, fruits, pulses, seeds and nuts are examples of these plants (AACC, 2001; Meister, 1996). The cell wall in plants is the primary location for these fibres, and their presence provides structural support to the plants (Anil, 2002; Babcock, 1987; Chen et al., 1988; Glitsø & Knudsen, 1999; Ozkaya, 1997; Park et al., 1997; Riaz, 2001; Uzunkaya & Ercan, 1999).

Dietary fibre is divided into two types:

1. Water-soluble fibre, such as gums, pectins, some hemicelluloses, and mucilages; fruits (especially citrus fruits and apples), oats, barley, and legumes are major food sources.
2. Water-insoluble fibre, for example whole grain breads and cereals, wheat bran, and vegetables (Thebaudin & Robertson, 1997).

The two types have an effect on the ways in which they can be used in baking operations due to the varying properties characteristic of water-soluble and water-insoluble fibres (Figuerola et al., 2005; Jaime et al., 2002; Katina, 2003; Schneeman, 1987). Water holding capacity, oil holding, swelling capacity, viscosity and gel formation are among the properties that are affected by the differences between water-soluble and water-insoluble fibre and these properties underpin the physiological effects of dietary fibre (Barbara & Robert, 2001; Femenia et al., 1997; Figuerola et al., 2005).

The composition of wheat bran is rich in various nutrients. Brouns et al. (2012) reported the nutritional benefits as well as the physiological nature of the aleurone layer which is rich in nutrients. They described these nutrients and their potential health-related effects. These nutrients include essential amino acids such as lysine and tryptophan, vitamins such as thiamine and niacin, antioxidants such as ferulic acid and alkylresorcinols, and minerals such as phosphorus and iron.

Many diseases may be prevented by consuming adequate daily levels of dietary fibre. Examples of some of these common chronic diseases include obesity, cardiovascular diseases, colorectal cancer, diverticular disease, hiatus hernia, appendicitis, varicose veins, piles, bowel cancer and gallstones (Cleave, 1956; Sidhu et al., 1999). Furthermore, epidemiological studies clearly demonstrated that the risk of gastro-intestinal cancers is reduced by consuming whole-grain foods (Anson et al., 2011; Chan et al., 2007; Hamer et al., 2008; Schatzkin et al., 2008). Serum cholesterol and postprandial blood glucose levels in humans are also reduced by regular consumption of soluble dietary fibre (Kahlon & Chow, 1997; Klopfenstein, 1988; McIntosh et al., 1991). This is due to the reduced absorption of components (e.g. glucose, bile acids, cholesterol) by the intestine and this reduced absorption results from the presence of sticky solutions formed as a result of the continuous consumption of fibres (AACC, 2001, 2003; Manthey et al., 1999; Newman & Graham, 1989). Insoluble dietary fibres have the ability to bind to water, which in turn softens the stool bulk and reduces the time of fecal material passing through the large intestine (AACC, 2001, 2003; Anderson et al., 1990; Asp et al., 1993; Manthey et al., 1999). It also found that some of the fibre compounds have a role in reducing cholesterol levels and glucose levels, these effects helping to prevent coronary disease and diabetes, respectively (Klopfenstein, 1988; Lu et al., 2000) .

Obesity is a problem that much of the world’s population in general suffers from, and in Britain in particular (HSE, 2019). Data from the Health Survey for England (HSE) conducted in 2018 indicated that 31% of adults in the United Kingdom were recognised as clinically obese (NHS, 2019). An advantage of fibre is that it does not contain calories and thus it is an important and essential component of the diet for combatting obesity. Furthermore, fibre helps to absorb water along the process of digestion, the first effect taking place from the mouth through to the stomach which causes swelling, and gives a feeling of fullness more quickly and for longer. The second effect of the fibre occurs in the remainder of the digestive system by aiding efficient digestion, and preventing bowel problems such as constipation (Anderson et al., 1990; Asp et al., 1993; Feldheim & Wisker, 2000). The Academy of Nutrition and Dietetics, formerly the American Dietetic Association, stated that the risk of obesity can be reduced by intake of 14 g dietary fibre per 1000 kcal consumed, and similarly with this amount of fibre, the risk of some diseases, such as cardiovascular diseases, and type 2 diabetes, has been reduced (Slavin, 2008).

According to a range of studies, the recommended amount of fibre intake is approximately 38 g per day for men and 25 g per day for women (Cummings, 1993; Gordon, 2003; Katina, 2003; Laurikainen et al., 1998; Sidhu et al., 1999). In spite of this, typical western diets do not reach the recommended quantity, containing less than 20 g per day (Anderson et al., 1990; Katina, 2003; Spiller, 1993). The incompleteness of the potential health benefits of fibre for most of the population has a negative effect on both individuals and national health services.

Some studies have shown few health benefits from fibre, in contrast to the majority of studies demonstrating the benefits. Increased fibre in the diet failed to reduce colon cancer (Vincent et al., 1995) and had no effect in the prevention and treatment of constipation

(Kochen et al., 1985; Preston & Lennard-Jones, 1986; Stahl & Berger, 1990). These contradictory findings may be due to the difference in individuals' response to fibre. Fibre may have a negative effect on occasion, for example causing irritation for some people, and it may be inoperative for others. As is known, human bodies are different in their response to medication and treatments, such that there is no single treatment that is effective for everyone. Overall, the majority of studies confirm positive benefits and demonstrate that increased fibre intake has positive effects on community health.

4.3 Bread as source of fibre

Bread is one of the oldest foods and is widely consumed among people, regardless of their beliefs and religions. From ancient times bread was a staple food for the Middle East and Western peoples. Nowadays, since bread has become an important staple food in the world, great efforts have been invested in optimizing the quality of bran-rich bread, which has proved to be a challenging task. Despite the harmful effects on the bread structure by addition of bran, it is widely acknowledged that palatable wholemeal breads have a positive role to play in increasing dietary fibre consumption (Campbell et al., 2008a; Zhang & Moore, 1997; Heinio et al., 2016).

Cereal fibre is the most beneficial fibre for health, compared to fibres from other sources. Cereal fibre can have specific health benefits, for example decreasing diabetes risk, where fruit fibre has had no effect (van der Kamp, 2004). Wheat bran is also characterized by low amounts of fat and relatively high amounts of fibre compared to some other fibre sources

(Uysal et al., 2007), as well as its desirable natural flavour, and being a good source of vitamins and minerals (Pomeranz et al., 1977).

Bran is a complex biological material, with a specific histological structure and a variety of chemicals, in addition to the physical properties of the component tissues (Shetlar & Lyman, 1944). Figure 4.1 shows a cross-section of wheat bran, regular wheat bran is made up of pericarp at a level ranging between 6-23% and is comprised of the epidermis, hypodermis, cross and tube cells, as well as 6-30% as a component of the seed coat and nucellar epidermis, 33% to 52% aleurone layer, and 9% to 35% starchy endosperm. Table 4.1 shows the overall chemical composition of regular wheat bran and the heterogeneous distribution of these components among the different layers, each of which has its own specific composition as shown in the table (Barron, 2011; Haskå et al., 2008; Nordlund et al., 2012; Parker et al., 2005).

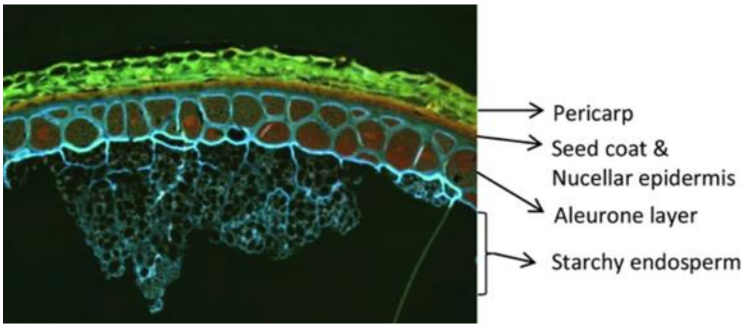


Figure 4.1 Cross-section of wheat bran (as produced from conventional milling) (Hemdane et al., 2015).

Table 4.1 Percentages of chemical composition and arabinose-xylose (A/X)-ratio of regular bran, pericarp, and aleurone (Brouns et al., 2012; Haskå et al., 2008; Hemery et al., 2009; Parker et al., 2005).

Components	Regular bran	Pericarp	Aleurone
Arabinoxylan	17–33	42–46	20–46
A/X-ratio	0.46–0.51	1.06–1.15	0.36–0.39
Cellulose	9–14	22–40	1–3
Fructan	3–4	n.a.	5[b]
β-D-glucan	1–3	3–9	5–16
Starch	6–30	0–6	0–11
Proteins	14–26	6–10	21–30
Lipids	3–4	0–1	4–9
Ash	5–7	2–7	7–12

b Only one measurement.

4.4 Effect of adding bran to bread dough

Since bread is an important staple food around the world, many researchers are making a great effort to improve the quality of bran-rich bread, but this is a difficult task, due to the diversity of mill-derived bran products and components of the different histological layers of bran. When studying the effect of adding bran to bread, the diversity in these bran-containing products should be taken into consideration, and that each of these parts may have its own characteristics and effect on the breadmaking. For example, coarse bran and coarse grinding are shown to be more harmful to bread volume than fine grinding and low-grade flour (Hemdane et al., 2015), while the pericarp is evidenced to have a more negative effect on the breadmaking than the more inner layers (Gan et al., 1992).

Using the bran in large quantities reduces the quality of baked loaf in terms of an unacceptable taste and undesirable texture (Gormley & Morrissey, 1993; Katina, 2003; Laurikainen et al., 1998; Oomah & BD, 1983; Salmenkallio-Marttila et al., 2001).

Consumers often prefer to consume bread with similar volume, texture and quality to white bread which contains many small gas cells. Many do not like bread that is high-density, brown and with a rough texture due to a high content of wholegrain or fibre (Başman & Köksel, 1999; Cauvain et al., 1983; Mann et al, 2015; Acevedo et al, 2019; Gambaro et al,2006; Heenan et al, 2008).

Many studies have reported the harmful effect of wheat bran on breadmaking and final loaf quality in terms of the functional and the sensory characteristics of bran (Campbell, et al., 2008a; De Kock et al., 1999; Galliard, 1986b; Lai, Hoseney, et al., 1989a, 1989b; Özboy & Köksel, 1997; Pomeranz et al., 1977; Seyer & Gélinas, 2009; Shogren et al., 1980; Zhang & Moore, 1997; Zhang & Moore, 1999). The addition of bran to the dough has different effects: increases water absorption and loaf weight, reduces loaf volume and specific volume, darkens crumb colour, coarsens crumb texture, reduces crumb softness, decreases dough strength, increases stickiness, decreases mixing and fermentation tolerances and can give a bitter flavour (Campbell, et al., 2008a, 2008b; Gan et al., 1992; Haridas Rao & Malini Rao, 1991; Lai, Davis, et al., 1989; Moder JR et al., 1984; Pomeranz et al., 1977; Rogers & Hoseney, 1982; Shetlar & Lyman, 1944; Zhang & Moore, 1997). It is found that the volume, colour and texture of bread loaf are affected negatively when bran is added; these negative effects increase with the increase in the amount of added bran as shown in Figure 4.2 (Zhang & Moore, 1999).

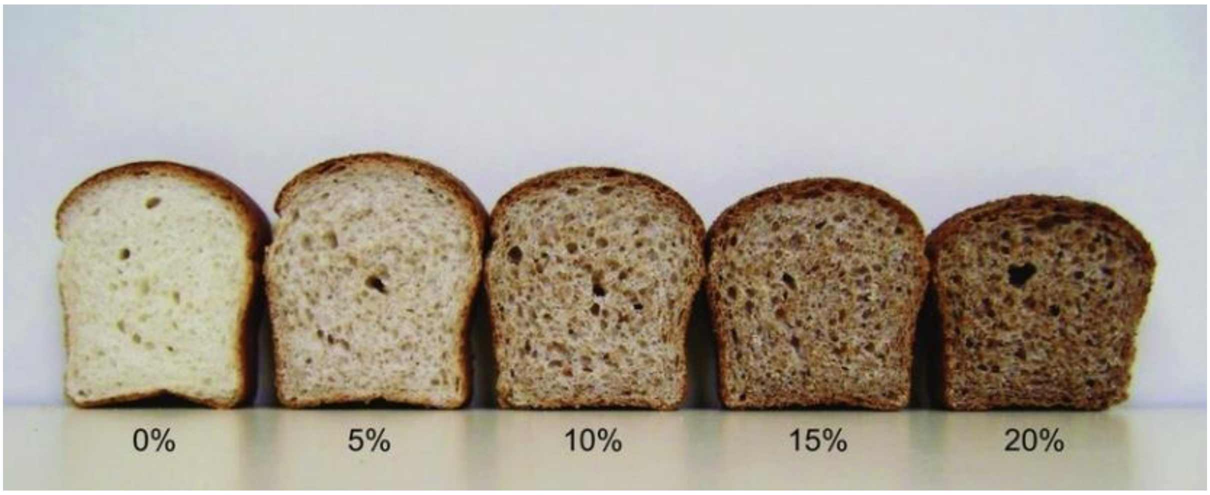


Figure 4.2 Effect of different levels of bran addition on loaf volume: bread loaf with out bran addition and bread loaves where 5%, 10%, 15%, and 20% flour was replaced by bran (Hemdane et al ., 2015)

Schmiele et al. (2012) found a reduction in specific volume from 4.4 cm³/g to 1.8 cm³/g when adding wheat bran at levels of up to 40% in bread. This concurs with findings of Campbell, et al. (2008a) who found a similar trend when adding wheat bran up to 15%. In addition to the decrease in the size of the loaf, Schmiele et al. (2012) observed a noticeable increase in crumb firmness and hardness when adding wheat bran or whole grains with higher concentrations, which can be linked to the smaller size of the final loaf. Crumb texture quality in final bread also decreased by incorporation of wheat bran, and a darker crumb colour can be observed (Majzoobi et al., 2013).

There has long been a debate among researchers about the extent of the damaging effects of bran on the palatability of loaves (Bloksma & Bushuk, 1988). However, the aim should be to reduce negative effects as much as possible to achieve a soft loaf texture. This is most successfully achieved by increasing the specific volume to be close to that of white loaves (Cauvain et al., 1983). Some researchers suggested reducing the detrimental effects on loaf volume, crumb softness and crumb structure by addition of water to the dough. The presence of bran increases the rate at which water is absorbed, reducing dough strength, and hence the aerated bread volume (Dreese et al., 1982; Haridas Rao & Malini Rao, 1991; Lai, Hoseney, et al., 1989a; Moder JR et al., 1984; Pomeranz et al., 1977; Zhang & Moore, 1999).

In the bread industry, over the past few years, some companies have utilised a number of different methods in order to improve the technological functions of bran and the sensory aspects that are usually associated with wheat bran. The first approach to reducing the harmful effect of bran on the breadmaking includes the use of flour with high protein content, the addition of water, processing adjustments, as well as addition of bread improvers such as surfactants, enzymes, and commercial gluten. The main aim of these enhancements is to enhance the gluten starch matrix and improve the stability of fermentation, which results in an increase in gas retention and expansion of the dough, which ultimately leads to obtaining large volume size of bread as well as improving colour characteristics significantly (Gan et al., 1989; Lai et al., 1989b; Moder JR et al., 1984; Penella et al., 2008; Shogren et al., 1980; Sidhu et al., 1999).

4.4.1 Mechanisms of bran effects

The detrimental effects of bran on bread dough and a deeper explanation thereof is still unclear, although research has been conducted in this area for many years (De Kock et al., 1999; Shetlar & Lyman, 1944). Various mechanisms have been suggested, involving two main categories of effects, physical and chemical (De Kock et al., 1999).

Several factors were attributed to the harmful effect found when adding bran in the breadmaking process. The dilution of gluten proteins is one of these factors (Moder et al., 1984; Pomeranz et al., 1977). Pomeranz et al. (1977) found that when adding bran in bread formulations at levels of less than 7%, the extent of reduction in volume of final bread matched the reduction expected from the dilution of gluten proteins by bran, but when adding more than this level, a volume of final bread reduction higher than that expected based on dilution of gluten was noticed. This gives an indication that gluten dilution is not the only mechanism by which the volume of bread is reduced (Galliard, 1986b; Lai et al., 1989b; Pomeranz et al., 1977). Moreover, physical, chemical, or biochemical properties of bran could be contributing to this negative impact.

One of the most significant detrimental effects resulting from the addition of bran is on the weakness of the viscoelastic structure, which in turn affects the overall structure of the bread (Zhang & Moore, 1999). Gluten films are physically affected by the disruption caused by the addition of bran particles, fundamentally due to gluten proteins in white flour being diluted when the flour is replaced with bran. This causes less oven spring, giving a lower volume of the final baked loaf (Gan et al., 1992; Pomeranz et al., 1977). However, in addition to the flour dilution factor, there is also another more noticeable reason for the reduction in the volume of bran-rich bread; a combination of mechanisms that in turn causes these observed effects (Dreese et al., 1982; Galliard & Collins, 1988; Gan et al., 1992; Lai et al., 1989a; Rogers & Hoseney, 1982).

Besides the fact that bran has an effect on dough development and quality due to the dilution of gluten proteins, the bran also might impede proper gluten development. The mechanism is that the bran particles impede the communication between the flour particles. This phenomenon is associated with a hypothesis of slow water uptake of bran. It can be explained that when flour is replaced by higher levels of bran causes an increase in the dough development time using Farinograph analyses (Sanz Penella et al., 2008), but when using Mixograph analyses, this phenomenon was observed to a much lower extent (Pomeranz et al., 1977).

Dough structure might disturb by bran particles by incorporation of bran particles into the gas cell walls of the dough matrix. This hypothesis explains the presence of bran particles in dough might force gas cells to expand in a certain distance (Gan et al., 1992), or coalescence or disproportionation of cells due to piercing gas cells, resulting in less gas retention in the dough structure and ultimately, low volume bread and dense bread texture of whole-grain bread. Gan et al. (1989) suggested that bran epicarp hairs play a predominant role in this effect due to chemical composition and arabinose-xylose (A/X)-ratio. It contains 22-40% Cellulose and 42-46% Arabinoxylan which are the largest amount comparing with other parts of wheat bran (see table 4.1 in section 4.3), and 1.06-1.15 A/X-ratio, which is arabinose to xylose ratio. It is higher than the A/X-ratio of other wheat bran parts, which indicates the presence of more branches and chemical bonds (Hemdane et al., 2015); this contributes to absorbing more water resulting in an increase in the dough development time. This effect can be reduced to a certain extent by removing bran epicarp hairs by pearling process prior to milling (Gan et al., 1989, 1992).

Regardless of the significant role of epicarp hairs, some studies of microscopic analyses of bran-rich dough (Gan et al., 1992) and bread (Pomeranz et al., 1977) have shown that bran particles somehow do cause a physical disruption of the gluten starch matrix. The specific stage of breadmaking in which the disruption effect is most pronounced is unclear and differs between the opinions of researchers. Campbell et al. (2008) suggested that it could be in the mixing stage when the gluten network begins to form or during the later stages of proving, and it may present itself during early baking stages while is the gluten network is stretched thin (Gan et al., 1989; Campbell et al., 2008).

The common belief in regard to the presence of bran particles in dough formulations is the destructive effect of this bran on the surface, and then the structure of the whole dough. The occurrence of this disruption maybe during the mixing process, during the slow expansion of the proving stage (Pomeranz et al., 1977; Wootton & Shams-Ud-Din, 1986) or during the baking stage in which the most rapid changes occur (Gan et al., 1992; Pomeranz et al., 1977; Shetlar & Lyman, 1944; Wootton & Shams-Ud-Din, 1986; Zhang & Moore, 1997). This physical disruption to the dough structure can be reduced using pearling of wheat kernels, which removes epicarp hairs, components that may be particularly damaging to the structure of gluten films within the dough (Gan et al., 1992).

Despite a known reason of decreased loaf volume being a reduced volume of gas within the loaf, this is not the result of less gas being generated in bran-enriched doughs (due to inhibition of the yeast), but rather by reducing the gas retained inside the dough (Pomeranz et al., 1977; Rogers & Hoseney, 1982; Sosulski & Wu, 1988).

It was concluded that the main effects of wheat bran on the aerated structure do not occur earlier during the breadmaking process, rather during the baking stage (Campbell et al., 2008). They found a weak correlation between the effect of wheat bran on expansion during fermentation and the loaf volume, however, some of the authors report that the disruptive effect could also occur during the dough stage. They found a decrease in dough strength and extensibility (Chen et al., 1988; Rao and Rao 1991; Zhang and Moore 1997; Sanz Penella et al., 2008; G´omez et al., 2011; Schmiele et al., 2012).

Adding water to the bran-enriched doughs affects the composition and the general structure of the dough. During the breadmaking process, this additional amount of water can be retained which in turn results in starch gelatinisation at lower temperatures during the baking stage contributing to the declining volume of bran-enriched doughs, resulting in heavier bread (Campbell et al., 2008; Campbell et al., 2008a; Dreese et al., 1982; Haridas Rao & Malini Rao, 1991).

Many researchers believe that this water behaviour is responsible for the effect of wheat bran on breadmaking. Penella et al. (2008), and Schmiele et al. (2012) reported that slow bran absorption kinetics in water compared to flour components prolongs the development time of the typical bran-rich dough. It is found that the harmful effects of bran on breadmaking are due to the bran's reaction in water; this is based on the fact that when adding 2% additional water (compared to the amount of water indicated by Mixograph absorption), it was observed that the bread loaf sizes increased (Lai et al., 1989b). It should be borne in mind that some of the different aspects of ameliorating the bran behaviour may have a strong link during the breadmaking, considering the dynamic condition of the process. For example, during dough mixing, the external pressure to which the bran is exposed makes the bran absorb only strongly-bound water. However, when this external effort disappears at the end of mixing stage, the bran tends to bind water that cannot be bound during the mixing (Hemdane et al., 2015). Some researchers agree that another reason for bran's detrimental effect is its dynamic hydration behaviour, suggesting that when the bran-rich dough absorbs the excess water, this then is available for starch gelatinization during baking, resulting in lowering the starch gelatinization temperature and finally in reducing the final bread volume (Dreese et al., 1982; Rogers & Hoseney, 1982). This hypothesis was supported by the findings of Roozendaal et al. (2012), that the water absorbed by the bran is released throughout the heating process.

The deterioration that occurs in the wholemeal flour is much faster than that which occurs in white flour; the main reason for this is the presence and accumulation of polyunsaturated fatty acids during storage. These fatty acids give lower quality baking and contribute to the reduced volume in final baked products (Galliard, 1986a, 1986b; Galliard & Collins, 1988; Tait & Galliard, 1988). Moreover, another potential explanation is the absorption of specific molecules of fat by bran, or during the storage, the bran causes them to be converted into fatty acids (Dreese et al., 1982).

4.4.2 Effect of bran particle size

Although there are health benefits of adding bran to bread, it has detrimental effects on the taste, texture and volume of bread, with the particle size of the bran having a significant role on the sensory characteristics of the bread.

The bran particle sizes used in studies are generally described as Coarse, Medium and Fine, although these descriptions are comparative rather than absolute or consistent between different studies. Sieve analysis is used to determine the particle sizes of bran fractions. The particle size of the three sizes varies from study to study. Generally, most bran particle sizes are larger than 500 µm before further fine grinding process while the typical endosperm particle size (the main component of the straight-grade flour) is lower than 150 µm (Rodriguez & Olivares, 2007). The median bran particles sizes are reduced to 90-440 µm by fine grinding (Zhang & Moore, 1997; Penella et al., 2008; Cai et al., 2014; Steglich et al., 2015). Doehlert and Moore (1997) prepared coarse, medium and fine bran by further grinding bran and passing it through 1.19, 1.00 and 0.60 mm screens, respectively, rather than sifting bran.

The effect of wheat bran particle size on final loaf volume is still unclear. Many researchers came to the same findings which showed that bread volume is affected more negatively with the use of fine bran compared to that with coarse bran (Campbell et al., 2008; De Kock et al., 1999; Galliard & Gallagher, 1988; Noort et al., 2010; Özboy & Köksel, 1997), indicating that the presence of particles of fine bran has a crucial role in disrupting the mechanical integrity of the dough structure; the numerous fine particles disrupt the gluten proteins more than the same amount of coarse bran consisting of fewer particles. Unlike medium or coarse brans, fine bran particles give lower loaf volumes and a denser appearance and crumb texture (Campbell et al., 2008; Campbell et al., 2008a; Collins et al., 1985; Collins & Young, 1986; De Kock et al., 1999; Zhang & Moore, 1997; Zhang & Moore, 1999). The Coarse bran gives open structure for the crumb more than Fine bran (Gonzales-Barron & Butler, 2005; Millar et al., 2019; Wang et al., 2017).

By contrast, several studies have shown that the fine bran particles give a higher final loaf volume and more ‘fluffy’ texture than when coarse particles are used, thus producing a loaf with properties closer to white bread. For this reason, numerous workers advise the use of bran with lower particle size as a suitable method of increasing the quality of bran-enriched breads (De Kock et al., 1999; Haridas Rao & Malini Rao, 1991; Lai et al., 1989a;

Moder et al., 1984; Nelles et al., 1998; Özboy & Köksel, 1997; Pomeranz et al., 1977; Rasco et al., 1991; Shetlar & Lyman, 1944).

As a result of the debate among researchers about the effect of size of the bran particles on the bread volume, some have found that using fine particles gave the smallest loaf volume, whereas others found that the larger-size particles gave the largest final baked loaf volume; this indicates that there can be an optimal particle size for minimising the damaging effects of bran in bread dough formulations.

In addition, focusing more on the optimum size of particles, Zhang and Moore (1999) found that medium-sized bran (415 µm) produced a larger specific volume of bread compared to both coarse bran (609 µm) and fine bran (278 µm). This is supported by Coda et al. (2014) who observed the highest specific loaf volume with the addition of wheat bran with an average particle size of 160 µm compared to that achieved with other bran particle sizes (750, 400, and 50 µm). However, in other studies it was reported that for certain types of wheat, there are no significant effects of bran particles on bread volume (Cai et al., 2014; Galliard & Gallagher, 1988; Özboy & Köksel, 1997; Sanz-Penella et al., 2012).

In addition, the reason for these differences between the bran particles size may be due to their ability to retain water. Cadden (1987, 1988) found the ability to retain water decreases as bran particle size decreases. Moreover, Zhang & Moore (1997, 1999) found that fine bran particles hydrate more rapidly during mixing and thus decrease the mixing time required for the bran-enriched doughs. They concluded that rather than being the result of any effects of chemical reactions within the doughs, or a result of physical factors relating to the structure of the dough, it is most likely these differences are related to water absorption rates between the two particle sizes.

4.4.3 Effect of bran on texture properties of bread

The structure of the cell depends on the external appearance and the compositional characteristics of bread and these properties of crumb can be analysed objectively by digital image analysis, complementary to that of subjective visual and sensory methods. C-Cell is one of the most advanced digital-imaging systems to evaluate the bread and fermented product quality. The system defines cell characteristics and external features using dedicated image analysis software. The porous structure of bread contains 70% of the gas in the starch protein network and this amount of gas is produced during dough proving (Mills et al., 2003). The most important factors for enhancing the quality of white bread is the stabilization of this gas network and the cell structure of the final product (Gonzales-Barron & Butler, 2005; Millar et al., 2019). The key indicator of carbon dioxide bubbles captured during proving is cell size, which has a clear effect on the crumb texture and sensory characteristics of final baked bread Small cell size within the bread gives a close crumb structure, resulting in a dense loaf (fine texture), while a coarse texture results from a larger cell size which gives an open crumb structure (Gonzales-Barron & Butler, 2005; Millar et al., 2019).

Among various baking properties of bread, area of cells (the total area of cells as a percentage of the total slice area), mean cell diameter (the average diameter of cells), wall thickness (the average thickness of cell walls) and coarse/fine clustering (the ratio of coarse cells to fine cells) are attributes which are key parameters when characterizing and evaluating bread crumb structure (Xu et al., 2018). A more open, elastic and softer texture, with a higher cell area and finer cells with thinner walls, is more widely accepted by consumers than a coarse, thick-walled cell structure (Wang et al., 2017). The increase in cell diameter and thickness gives an indication that the dough is unable to retain gas, resulting in fusion of cells and formation of large-diameter cells, and even forming unattractive holes during proving and baking (Ning et al., 2017).

The brightness of the loaf crumb depends on the size and shape of the gas cells; finer grain cells give more brightness than larger cells that contribute to greater shadows and lower brightness values (Gostin, 2019; Lin, 2008). Gostin (2019) found correlation coefficients of −0.637 and 0.971 for brightness with cell volume and number of cells, respectively, when studying the effect of substituting refined wheat flour with wholemeal and quinoa flour on the technological and sensory characteristics of salt-reduced breads; this study also found a negative correlation coefficient of −0.885 between fibre content and number of cells within crumbs. Gostin (2019) also showed that bread containing a small amount of fibre is characterized by high brightness values, low cell size and a large number of cells, while there is an inverse relationship to bread made from flour containing a high percentage of fibre. Previous work has similarly shown that adding fibre reduces the number of cells in the bread structures (Noort et al., 2017). Furthermore, dietary fibre competes with gluten proteins for water, which results in hindering the formation of the gluten network (Turfani et al., 2017).

Small gas cell diameters are seen as a positive in bread loaves (Başman & Köksel, 1999; Cauvain et al., 1983) and milling of bran particles is one of the recommended steps for production of high-quality loaves (Collins & Hook, 1991; De Kock et al., 1999; Haridas Rao & Malini Rao, 1991; Hook, 1987; Lai et al., 1989a; Moder JR et al., 1984; Moss, 1980; Nelles et al., 1998; Özboy & Köksel, 1997; Pomeranz et al., 1977; Rasco et al., 1991; Shetlar & Lyman, 1944). Although the presence of small cells in loaves is considered a beneficial feature, the decrease in overall volume is not. The presence of bran, especially fine bran, reduces the overall volume of loaves, this is due to the effect of small particles on the gluten network, which causes them to weaken and reduces their ability to retain gas (Noort et al., 2010). This results in less cell growth and consequently a smaller and denser loaf.

There are limitations in measuring the diameter of a gas cell in a slice of bread using the C-Cell. Thompson (2008) found that bran influences the thickness of the walls of the gas cells, with the highest values being recorded in the dough with the Coarse particles. Thompson also found that there is a close correlation between the thickness of the wall and the gas cell diameter, due to similar patterns in the directions of each of them. Thin cell walls may be a useful feature in improving the quality of baked products and making them more desirable, and adding bran may cause harm (Courtin & Delcour, 1998; Si & Drost-Lustenberger, 2002; Sørensen, 2003).

4.4.4 Effect of bran on the water absorption of breadmaking flour

Dough is often characterized using experimental rheology devices, the most commonly used being the Brabender Farinograph, while more recent devices with extended capabilities include the Perten DoughLab and the Chopin Mixolab. The Farinograph measures torque during the mixing of a dough in a defined geometry, from which information about the flour water absorption and the mixing characteristics of dough is derived. The Farinograph can be used with a 300 g, 50 g or 10 g mixer bowl. The parameters obtained from the Farinograph include water absorption, dough development time and dough stability.

The Chopin Mixolab is a similar empirical rheometer that measures the torque (Nm) in real time as the dough develops produced by mixing of the dough between the two kneading arms (Anonymous 2005), then extends the measurement during controlled heating and cooling of the dough, providing additional information on the behaviour of the protein and starch, and showing a simplified graphic presentation of the results based on 75 g of dough sample. The Mixolab has been used for the determination of rheological behaviour of wheat flour partially substituted with flour of non-wheat cereals (Aprodu & Banu, 2017; Chakraborty et al., 2018). Rheological properties, such are the water absorption, stability time, elasticity, viscosity and pulling attributes are substantial for milling and confectionary manufacture in terms of forecasting the parameters of processing the dough and characteristics of the baked products (Jusra et al, 2007).

Bran is characterized by its high ability to absorb water in large quantities. Recently, Jacobs et al. (2015) found that “water binding mechanisms on macro-, micro-, and nanoscale, and on a molecular level allow bran to retain water either weakly or strongly. Water retention by bran on a macroscale is ascribed to filling of void spaces in between bran particles, which arise from random stacking of bran particles”. (Stone, 2006) also reported that the spacing in between pericarp tissue layers affects water retention. Chaplin (2003) reported another way to retain the water, which is that the bran is rich in sugars and thus these sugars link water at the micro level through the formation of hydrogen bridges. These mechanisms contribute to water uptake by bran in the case of unconstrained hydration. The size of wheat bran particles does not affect the retention of the water during the application of an external voltage to the dough; this is attributed to the fact that the average particle size from 80-1600µm does not significantly affect the ability to bind water attributed to the nanopores or through hydrogen bonds (Jacobs et al., 2015).

Understanding and studying the influence of the size of bran particles in determining the capacity to absorb water is important to assess the performance of the breadmaking flour. Morton (1987) states that, in addition to the gluten quality, the amount of water absorbed by flour is responsible for the optimum development in the dough.

Looking at the effect of bran particle size reduction on properties of dough, Liu et al. (2016) found reducing bran particle size decreases the water absorption of dough. Nevertheless, Xu et al. (2018) found that the water absorption increased with the reduction of bran particle size by medium or superfine bran compared with the coarse bran. Large bran particles have been found to take up more water in comparison with that of smaller particles, based on the traditional water retention capacity, the swelling capacity, and Enslin water absorption tests (Jacobs et al., 2016). The Enslin Neff device can be used for measuring the water absorption rate of the tablets, the water absorption rate can be calculated from the volume difference of the absorbed liquid and the wetting time (Stoniš et al, 2015). However, it should be examined how accurately these tests represent the actual water-binding behaviour of bran during breadmaking (Hemdane et al., 2018). Reduced wheat bran particle size after fine (median diameter from 206 to 164 mm) and superfine (median diameter from 125 to 43 mm) grinding processes increased the Farinograph water absorption of reconstituted WWF (Niu et al., 2014a; Niu, Hou, Wang, & Chen, 2014b).

Other studies, however, reported that water absorption was independent of bran particle size (Jacobs et al., 2016; Zhang & Moore, 1997). This is consistent with Jacobs et al. (2015) who described the hydration mechanisms of wheat bran. They stated that the size of wheat bran particles does not affect the retention of the water during presence of an external effort to the dough; this is attributed to the fact that the average size of particle from 80-1600 μm does not significantly affect the ability to bind water attributed to the nanopores or through hydrogen bonds. However, some studies reported that fine bran has a higher water absorption than coarse bran, as measured using a Farinograph. This observation is attributed to the fact that the specific surface of fine bran is increased and exposed to hydroxyl groups (Cai et al., 2014; Noort et al., 2010; Penella et al., 2008).

Some studies found a reduction of bran particle size contributes to an increase in dough water absorption (Cai et al., 2014; Niu et al., 2014). In addition to the damaged starch content, it may be that the reason for increased absorption of dough water is the increase in the surface of the milled bran, which contributes to the rapid increase of water absorption at the short mixing time (Campbell et al., 2008a).

Xu et al. (2018) found that the addition of coarse bran into white flour improved the development time of dough. This is because of the long period of water absorption required by the coarse bran (Liu et al., 2016). They also found dough development time decreased as bran particle size became smaller, but Fine bran could increase the stability time of dough, which might result from the faster absorption of water by wheat bran of finer particle size (Penella et al., 2008). A study by Liu et al. (2016) found that with reduction of particle size (from ~175 µm to ~130 µm), the mixing stability time for three classes of U.S. hard whole wheat flours increased using Mixolab analysis. They also found that fine bran particles may have a less destructive effect on gluten network formation in dough. This may be attributed to the fact that the water-binding capacity of fibre was reduced with decreasing bran particle size (Le Bleis et al., 2015; Noort et al., 2010).

In addition, Farinograph measurement showed a decrease in dough mixing time and mixing stability when using fine bran particles compared with coarse bran particles. The longer development time of the dough with coarse bran is attributed to the fact that coarse bran particles need more time to absorb water than fine bran (Penella et al., 2008). As for the decrease in dough stability, it is probably due to the large number of particles present in the fine bran, which in turn gives a more severe disruption of the gluten network as a result of increased contact between the small particles (Penella et al., 2008). Zhang and Moore (1997) found the opposite of the above; they reported that dough with fine bran (278 µm) was less tolerant to mixing than dough with coarse bran (609 µm) as analysed by Farinograph.

The increased stability of dough can be explained by the mechanism that fine grinding of bran increases the surface of the bran particles, resulting in interactions in fibre molecules through hydrogen bonding involving the increased hydroxyl groups present (Rosell et al., 2010). Xu et al. (2018) found addition of bran into white wheat flour resulted in lower C3 values, which is the maximum torque during the Mixolab heating stage and represents the degree of starch gelatinization. This could be attributed to lower starch content or high enzyme activity in the bran. It showed a significant increase in the values of C3 with reduction of wheat bran particle size by medium or super-fine grinding.

C3-C4 values, which reflect the hot-gel stability/amylase activity of dough, decreased with the reduction of particle size. This indicates a lower amylase activity and a more stable starch gel. C5, the maximum torque of the cooling stage, which reflects starch retrogradation, increased with the reduction of bran particle size (Xu et al., 2018). Other studies have confirmed that finer bran induced more starch retrogradation than coarser bran.

Steamed bread can also contain added bran, and its quality is also affected by the size of the bran particles. Due to the different production methods (steaming and baking), steamed bread has a higher water content than baked bread. Accordingly, starch retrogradation and crumb-staling in steamed bread could be a bigger problem than in conventional bread (Cai et al., 2014; Liu et al., 2016).

Pena et al. (2006) found a strong correlation between the Mixolab dough development time, stability, and breakdown parameters and the dough strength parameters of the autograph when testing the whole grain flour. However, there are insufficient studies concerning the application of Mixolab to assess suitable wheat varieties in the breadmaking quality.

Xhabiri et al. (2016) studied the rheological qualities of dough from the mixture of flour and wheat bran and possible correlation between bra bender Farinograph and Mixolab Chopin equipment.

They observed that increasing the amount of bran from 5 to 20 %, increases the water absorption for doughs. These results indicate compliance with the results obtained by Gomez et al. (2003). They also found that there is a strong positive correlation of water absorption using Bra bender Farinograph and Chopin Mixolab with a correlation coefficient from $r=0.81$ ($p<0.05$) and $R^2=0.65$, which renders the important possibility for it to be used in the future for the determination of the quality of the dough.

Values of C1 and C2 expressed in Nm (the dough development and stability of proteins) are increased by adding bran (Xhabiri et al., 2016). These results are similar to the results of Banu et al. (2012), who have used wheat bran from 3% to 30%, whereby by adding 20% of bran, the stability of dough increased and then it started to decrease. Through the analysis on the correlation of dough development time using Bra bender Farinograph and Chopin Mixolab, Xhabiri et al. (2016) observed that there is a strong positive correlation of water absorption with a correlation coefficient from $r=0.84$ ($p<0.05$) and $R^2=0.70$. These results agreed with the results of Dapcevic et al. (2009) who used nineteen samples of mercantile wheat, and through the conducted analysis, a strong positive correlation coefficient is found with $r=0.96$ ($p<0.0001$). However, through in analysis of the correlation of dough stability by using Bra bender Farinograph and Chopin Mixolab, a poorly positive correlation is found with a correlation coefficient from $r=0.27$ ($p<0.05$) and $R^2=0.07$. These results significantly disagree with those of Rosell et al. (2010) who have used different commercial dietary fibres and obtained a correlation coefficient of $r=0.77$ ($p<0.05$). Dough development time is strongly influenced by protein and starch properties, type and flour particle size of used flours. The dough development time is longer in the case of good gluten quality compared within the case of poor gluten quality (Dabčević et al., 2009). As it is the case of gluten properties, the dough development time is not affected by starch properties (Catteral, 1995; Rasper & Walker, 2000). Dough stability is affected fundamentally by the quality of gluten and its impedance to the kneading forces. Some factors have effects on the Gluten properties, such as wheat variety, agroecological conditions during wheat growing, protease activity, milling conditions etc. (Catteral, 1995; Rasper & Walker, 2000).

Xhabiri et al (2016) also found that values of C3 (the gelatine capability of starch) and C4 (activity of amylase) decreased by the addition of bran. The reason for the decrease of the above-mentioned values is due to the fact that bran is usually the covering of the grain which contains a high amount of α-amylase. Through the analysis of the correlation between the results obtained from Bra bender Amylograph and C3 torque-Chopin Mixolab, they found a positive in an average of coefficient of correlation is with $r=0.38$ ($p<0.05$) and $R2=0.1482$. Adding wheat bran to the wheat dough may significantly interfere with protein binding and additional aggregation in the case of heating. Presumably, the space of the proteins in the gluten network is occupied by the presence of fibre (Gan et al., 1992), as well as the fibre has effects on the pasting characteristics of starch such as peak viscosity, breakdown and final viscosity (Santos et al., 2008). Values of C5, which is the cooling stage, indicates the retrograding attribute of starch. Xhabiri et al. (2016) observed the decrease in the values C5 with the increase of bran in the wheat flour; these results agree with the results of Rosell et al. (2010) who used different fibres such are fibruline, fibrex, exafine and swelite, in various ratios with flour. The slope γ or slope of the curve between C3 and C4 in all the mixtures is negative.

4.5 Summary

Although fibre has many significant health benefits, and bread is a significant contributor to dietary fibre, most people prefer to consume white bread (Mann et al, 2015; Acevedo et al, 2019; Gambaro et al,2007; Heenan et al, 2008; Foster et al,2020). This is largely because of the detrimental effect on the volume, crumb texture and flavour of the baked loaf when adding fibre to bread formulations. The relationship between these negative effects on dough aeration is summarised by the fact that the bran particles have a destructive effect on the dough aeration during the mixing, proving and baking stages of the bread-making process. Moreover, bran particles of different sizes have a different effect on the rheological properties of flour, such as water absorption and development time and stability time of the dough.

The next chapter presents in detail the materials, equipment and procedures used in performing the study of dough sheeting and gas retention for both white flour doughs and bran-enriched doughs.

Chapter 5. Materials and methods

5.1 Introduction

In this chapter, the details of materials and methods used to investigate the effects of sheeting on the development of bread dough are discussed. The emphasis is on the number of sheeting passes applied to the dough, and the gap between the rolls, in order to understand the effect of sheeting on the ability of non-bran-enriched doughs and bran-enriched doughs to expand and retain gas. The effectiveness of sheeting compared with development by mechanical energy input in the dough mixer is examined. In addition, the details of materials and methods used to bake the bread and investigate the effects of sheeting on quality of final baked loaves for doughs formulated with different levels and particle sizes of wheat bran. are presented. The details of materials and methods used to estimate water absorption of dough with bran are explained as well in this chapter.

5.2 Materials Used

5.2.1 Flour and other bread ingredients used in dough preparation

Table 5.1 show the ingredients used for dough preparation and their sources. Doughs were prepared from flour, salt, yeast, fat, sugar and water, with and without bran. Strong wheat flour and coarse bran were obtained from Allinson, Peterborough, PE2 9AY. Salt was obtained from Tesco Stores (Cheshunt, UK), and yeast and fat from the local Sainsbury's in Huddersfield, sugar was obtained from ACROS (New Jersey, USA).

Table 5.1 List of ingredients and their sources

Materials	Details
Strong white flour (12 g protein/100 g)	Allinson, Sugar Way, Peterborough, PE2 9AY
Salt	Sainsbury's cooking salt, Sainsbury's, London, EC1N 2HT
Sugar	ACROS, New Jersey, USA
Water	Tap water, University of Huddersfield
Yeast	Fast action dried yeast, Sainsbury's, London, EC1N 2HT
Fat	Trex vegetable fat, Princes Limited, Liverpool, L3 1NX
Bran	Allinson, Sugar Way, Peterborough, PE2 9AY

5.2.2 MajorPin mixer

The Simon Majorpin mixer (Henry Simon Ltd., England) used in this work is shown in Figure 5.1. It is a pin mixer in which four pins in the upper head rotate in a planetary motion that interweaves with the fixed pins in the bowl. Its capacity is 3 litres. It is not a high speed mixer and does not develop the dough extensively; in the current work it was used just to form the initial dough, with minimal development, in order that most of the development occurred via sheeting.

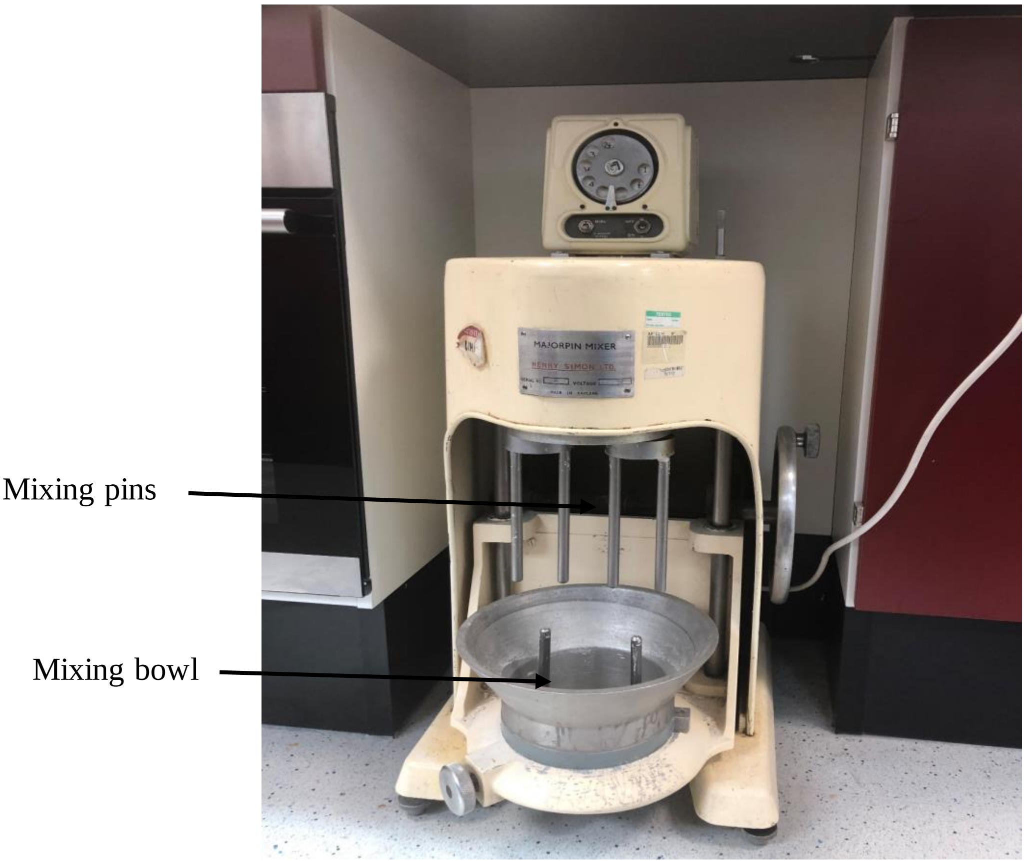


Figure 5.1 Majorpin mixer

5.2.3 The Tweedy Mixer

The Tweedy 1 mixer is a small-scale version of Tweedy mixers widely used in industry. During the development of the Chorleywood Bread Process (CBP) in the 1950s, based on mechanical dough development in a high speed batch mixer, it was found that on scale-up of the mixer, the dough became too aerated. The solution was to mix under a partial vacuum, which became a feature of the CBP and of the Tweedy mixers that were at its heart. Numerous countries worldwide use the Tweedy mixer for producing the bread, such as Australia, New Zealand and the UK. The Tweedy 1 mixer is a scaled-down version, unique to our labs, with the name “Tweedy 1” based on its nominal capacity of 1 lb of flour (454 g, although in practice we use 400 g as standard). The Tweedy 1 mixer is arguably the most versatile mixer in the world for dough mixing studies; it can be operated under partial vacuum or under positive pressure, and at different mixing speeds, while in the past it has also been used for studies of different compositions of gas in the headspace. It has been the basis for numerous previous studies of bread dough aeration (Chin et al., 2004; Chin & Campbell, 2005a, 2005b; Chin et al., 2005; Martin et al., 2004; Martin et al., 2004), and this is what distinguishes it from the MajorPin mixer used in this this study, which lacks such important features in baking tests. In the current work Tweedy 1 mixer is being used for the first time in combination with dough development by sheeting.

Figures 5.2-5.3 illustrate the Tweedy mixer. The mixer blade is placed at the bottom of the mixing bowl. It is joined to a central rotary spindle, and it has an octagonal base with two helical paddles. The blade shape gives a good shearing action during mixing. The presence of three baffles around the sides of the mixer bowl creates an obstruction that helps to rotate the dough to ensure effective mixing. The top of the mixer bowl is lined with neoprene. To ensure a sealed environment, the lid is fully mounted on the mixing bowl. An airtight environment is necessary to preserve the headspace pressure. To change the headspace pressure or composition, a gas pipeline can be linked to an attachment point. The rate of changing headspace composition and pressure is affected by the degree the valves are open.

The Tweedy 1 mixer is connected to a computer data collection, shown in Figure 5.4. The computer records the mixing speed and torque measurements with time (although at the time of writing, this has not yet been recommissioned following the move of this mixer from its previous home in the University of Manchester).

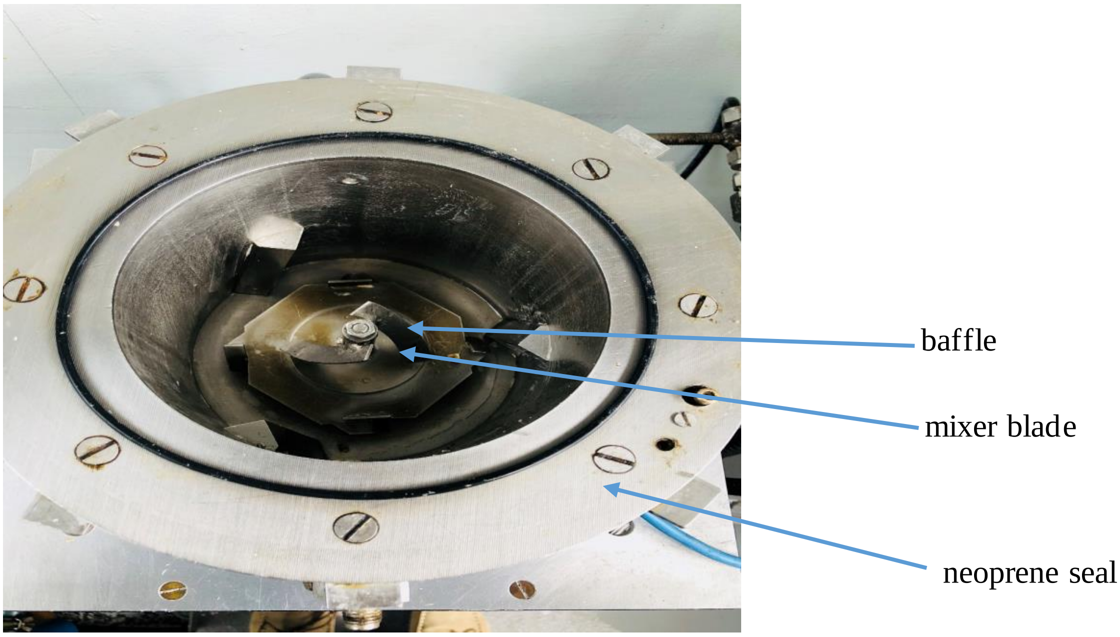


Figure 5.2 Inside the Tweedy mixer

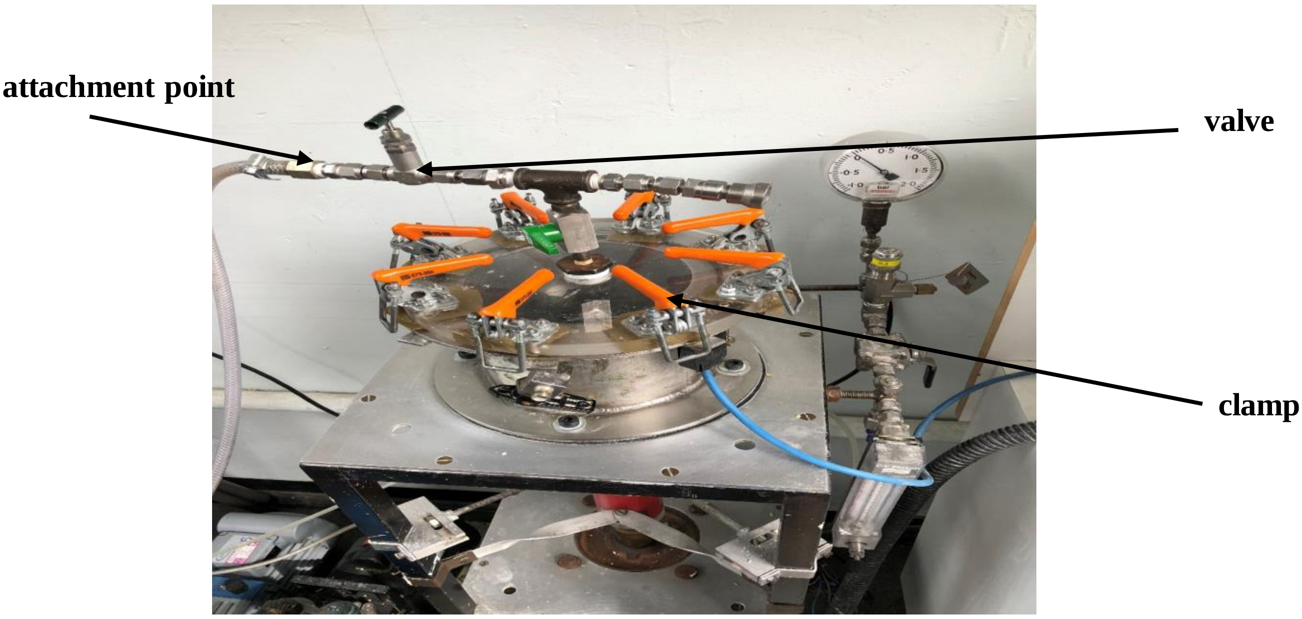


Figure 5.3 Outside the Tweedy 1 mixer with mixer lid in position

Figure 5.4 Tweedy 1 mixer set up with computer recording of speed and torque

5.2.4 Sheeter

Figure 5.5 shows the Rondo sheeter (Rondo Bergdorf AG, Switzerland) which is a hand-operated device that passes the dough from conveyors belts either side between a pair of rollers. Although the Rondo Company no longer manufactures this model, there are similar models available in the market. The range of thickness between the rolls can be varied from 23 mm down to 1 mm as the minimum sheeting thickness.

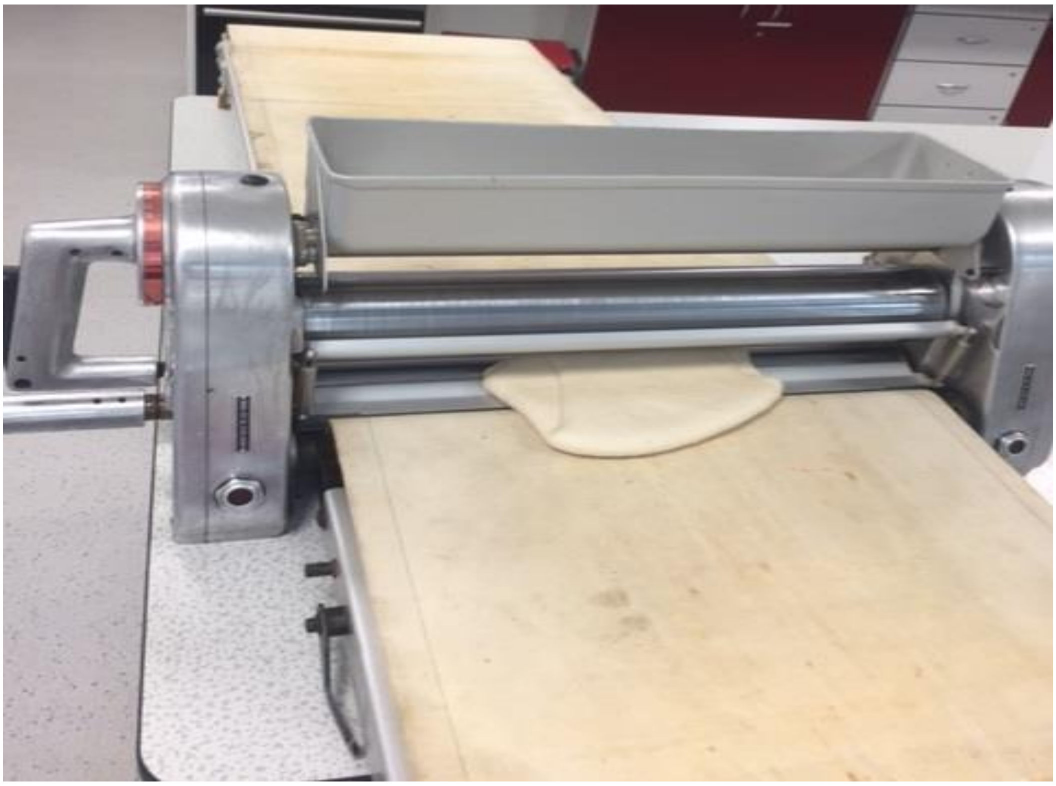


Figure 5.5 Rondo Dough sheeter

5.2.5 Texture Analyser

The texture of final baked loaves was measured using the Stable Micro Systems Texture Analyser, model TA-XT2 (Stable Micro Systems, Godalming, UK), shown in Figure 5.6. Loaf hardness was measured by testing a 25 mm thick slice. The slices were taken by dividing the final loaf into four equal pieces of thickness each of 25 mm thick. Hardness was measured using a P36 flat cylindrical probe of 36 mm diameter compressing the slice to a strain of 40%, with hardness taken to be the maximum force (in Newtons).

Figure 5.6 Texture analyser, TA-XTiCON

5.2.6 DML 30 mm Digital Depth Gauge

Figure 5.7 shows the Stainless Steel Digital Depth Gauge used for measuring the thickness of dough pieces following sheeting. It is made by Digital Micrometers Ltd, Model Number DDG100. The range of the Gauge is 0-30 mm with a resolution of 0.01 mm and accuracy of 0.02 mm. It has a 2 mm diameter depth pin and a 60 mm wide base.

Figure 5.7 Digital Depth Gauge

5.2.7 C-Cell Colour System

C-Cell is an advanced digital imaging system to evaluate the structural features of bread and bakery products (Calibre, 2016). Figure 5.8 shows the C-Cell Colour, which is the most advanced model with many software options available to analyse a full range of bakery products. The system defines cell characteristics and external features using dedicated image analysis software. C-Cell is manufactured and distributed by Calibre Control International in UK, who kindly lent the system to the University of Huddersfield for two months, to allow a study of bran and sheeting effects on bread structure to be undertaken within the current project.

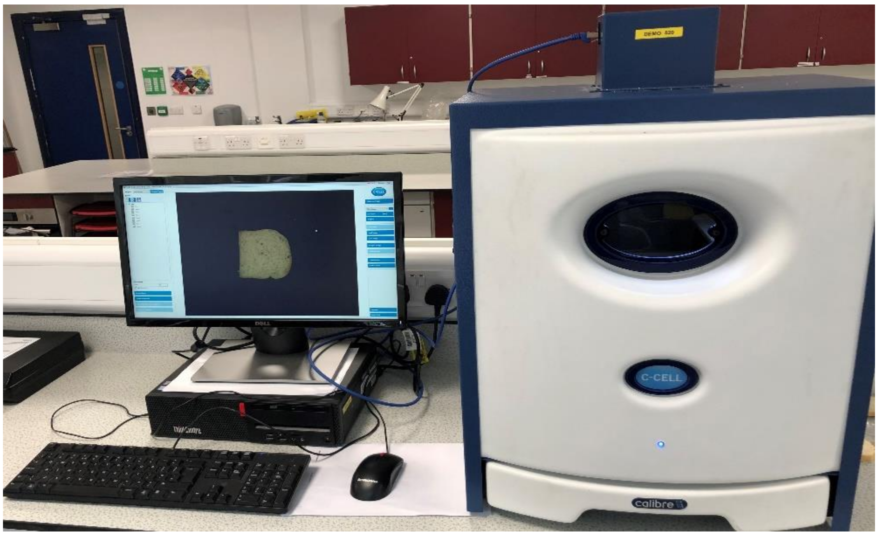


Figure 5.8 C-Cell Colour System

5.2.8 EinScan-SP 3-D scanner

The EinScan-SP 3D scanner is made by Shining 3D in UK, founded in 2004, which is pioneering independent research and the development of 3D digitizing and 3D printing technologies (Shining3D, 2019, July 14).

Figure 5.9 shows the EinScan-SP 3D scanner, which comprises a projector with a turntable (onto which the sample is placed), connected to the computer that contains the software to collect and analyse the data. It was used in the current work to measure the volume of baked loaves using the new AACCI- standard method for volume measurements (AACCI 10-14.01) (Anderson et al, 2014; AACC International, 2010)

Figure 5.9 Einscan-SP 3D

5.2.9 Mixolab

The Mixolab 2 is a dough testing instrument developed by Chopin Technologies (Villeneuve-la-Garenne, France), in which the torque exerted on the dough during mixing and heating is measured. Similar to other dough testing instruments such as the Brabender Farinograph, the Mixolab indicates the effect of flour properties and dough ingredients on dough development and stability. It also allows the appropriate water absorption for a flour to be determined, by calculating the required water addition to achieve a specified torque of 1.1±0.05 N m (water absorption, %). By continuing to measure the torque during heating of the dough, the Mixolab gives additional information about the time to reach maximum torque at 30°C [C1 time (dough development time), min], the elapsed time that the torque was kept at 1.1 N m (stability, min) starch gelatinization (C3, N m), stability of the hot formed gel (C3-C4, N m), and starch retrogradation (C5, N m) during the cooling phase

The standardized protocol (ICC N 173, AACC54 - 60.01 and NF V 03 - 764) is used in this Mixolab to give an accurate characterization of the flour (protein network, starch and enzyme activity), it also shows a simplified graphic explanation of the results (Chopin, 2012).

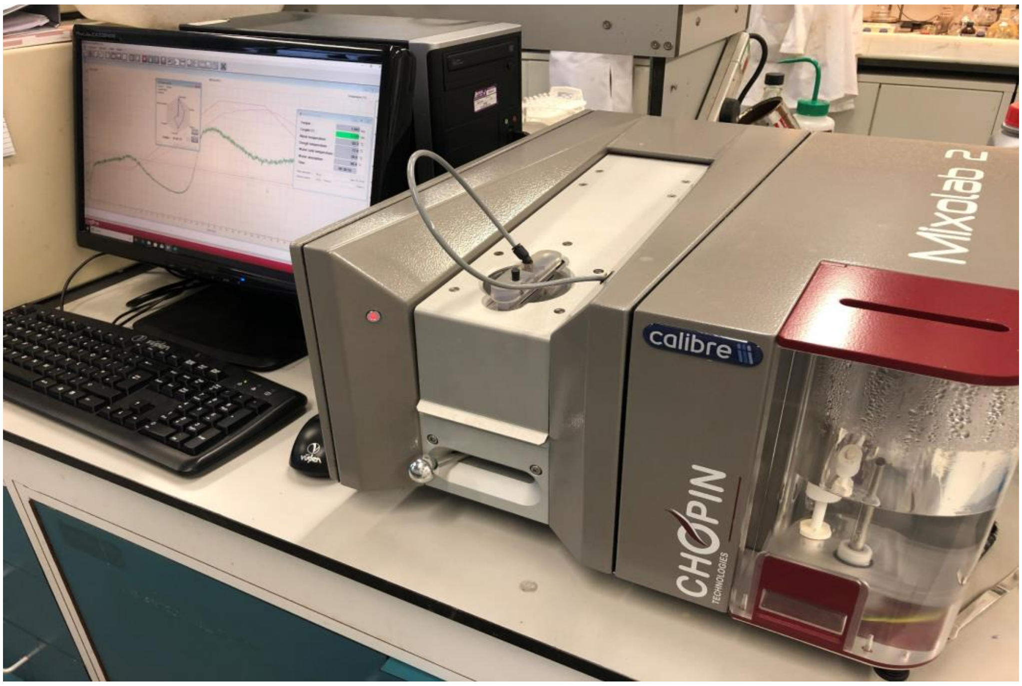


Figure 5.10 Chopin Mixolab 2.

5.3 Equipment and Procedures

In order to study the effect of sheeting regimes on dough development, the Majorpin mixer and Tweedy mixer were used to mix doughs for different mixing times, after which the doughs were sheeted in the Rondo sheeter up to 12 times, and their ability to expand and spring back quantified using the Dynamic Dough Density system (DDD) and Digital Depth Gauge, respectively. For studies that included baking, the final bread quality was assessed using the Texture Analyser, EinScan-SP scanner and C-Cell colour system. This section details the equipment and procedures used for these experiments and analyses.

5.3.1 Bran milling and particle size determination

Commercial Coarse wheat bran was obtained from Allinson, Peterborough, PE2 9AY, UK. To obtain Medium and Fine bran samples of the same composition, this Coarse bran was milled using a Retsch grinder ZM 1000 mill (Retsch UK Ltd., Hope Valley, UK) at a speed of 10,000 rpm and a screen aperture of 0.5 mm to obtain Fine bran. To obtain a Medium bran, the Coarse bran was milled using a Newtry grain grinder (Newtry UK) at a speed of 2600 rpm and load power 2000 W for 5 minutes.

The size distributions of the Coarse, Medium and Fine bran particles were measured by sieve analysis using an Endecotts Ltd. mechanical sieve shaker (model EVS1) and stainless-steel mesh sieves (2 mm, 1.7 mm, 1.4 mm, 710 µm, 355 µm, 180 µm, 90 µm and 53 µm). 100 g of each bran sample was placed on the top sieve and shaken for 15 minutes at a vibration intensity of 30%. The bran remaining on each sieve was collected and weighed to 1 decimal place using an Ohaus balance. Triplicate data were obtained for all three samples.

5.3.2 Dough preparation

Dough samples were prepared from white flour (Allinson flour, 100%), 1.5% sugar, 4% yeast, 1.6% salt, 5% fat, and water for control doughs (the amounts of ingredients are reported in Table 5.1, with the percentages of ingredients based on flour weight). Doughs were prepared based on 400 g flour. Flour, wheat bran, salt and sugar were weighed to an accuracy of 0.01 g using a Precisa 125A balance. Water, fat and yeast were measured using Ohaus Adventurer weighing scale to an accuracy level of 0.001 g. The doughs and final baked loaves were weighed to an accuracy of 0.1 g using the Precisa Junior 5000D balance (Precisa company for Weighing Equipment, Class I & Class II balances, UK & Ireland, UK).

In bran-enriched doughs, wheat bran (Coarse, Medium or Fine) was substituted for white wheat flour at different percentages (5, 10 and 15%) as showing in Table 5.2, in line with previous studies of bran effects in bread (Campbell, et al., 2008a, 2008b).

The water absorption used for the Control doughs without bran was 61%. Bran absorbs water, such that extra water is required in bran-enriched doughs to maintain the dough rheology and handling properties. Following the guidance of Campbell et al. (2008 a, b, c), the water absorption was increased by a percentage equal to half the percentage substitution of bran. For example, for dough in which flour was substituted with 10% bran, the water absorption was increased by 5% to 66%, corresponding to 264 g of water for 400 g of (flour + bran). Table 5.2 shows the additional water added.

Table 5.2 List of ingredients and the amount of water required for dough formulation.

Dough formulation	Quantity of flour used (g)	Quantity of fibre used (g)	% water required	Water required (g)
Control	400	00.00	61.00	244
5% wheat bran	380	20.00	62.50	246
10% wheat bran	360	40.00	66.00	264
15% wheat bran	340	60.00	68.50	274

5.3.3 Static and Dynamic Dough Density Measurements

Dough aeration was quantified by measuring dough density (Campbell et al., 1993), while the Dynamic Dough Density technique (DDD) was used to quantify the ability of doughs to expand and retain gas. The DDD technique was introduced by (Campbell et al., 2001) and developed by Campbell et al. (2008a-b). Figures 5.11 and 5.12 show the balance and double cup system used for measuring density of dough. For measuring the dough density without yeast (static dough sample such that no gas is being produced) the procedure is as follows:

First, the sample is weighed in air using an Ohaus balance accurate to 0.1 mg, after which the sample is immersed in xylene using the double-cup arrangement as in Figure 5.12, and weighed again. From the difference in weights, the sample's density, ρ, is calculated as:

$$\rho \qquad = \qquad \frac{m_{air}}{m_{air} - m_{xylene}} \rho_{xylene}$$

where:

m_{air} = weight of dough sample in air

m_{xylene} = weight of dough sample in xylene

ρ_{xylene} = xylene density

The gas content, ϕ, is calculated as;

$$\phi = 1 - \frac{\rho}{\rho_{gf}}$$

where;

ρ_{gf} = dough gas-free density

The gas-free dough density can be measured by mixing doughs at different headspace pressures and extrapolating back to zero pressure (Campbell et al., 1993). This requires a mixer capable of mixing at different pressures and was not done in the current work; instead density measurements were plotted directly, with the assumption that sheeting would have more effect on the gas content of the dough than on its gas-free density.

Measurement of Dynamic Dough Density requires yeasted dough samples which are left in the density meter for up to 1 hour, during which the changing density is recorded. Figure 5.11 shows the four DDD systems used in the current work. Each jacketed beaker is filled with xylene to the 500 mL mark. Samples are weighed in air and then immersed in xylene using the double cup system supported carefully on a Precise Electronic Balance (Figure 5.12). The whole system is connected to a water bath at 40°C, which distributes water around the jacketed beakers to heat the xylene to 38°C, the temperature at which doughs undergo proving. Xylene is used instead of water due to low its density and non-dissolving/non-wetting property; however, xylene is flammable and carcinogenic, so the system is operated in a fume cupboard. Temperature and weight data are recorded every 10 seconds on a computer running a LabVIEW 6.1 programme to monitor the four DDD systems in parallel.

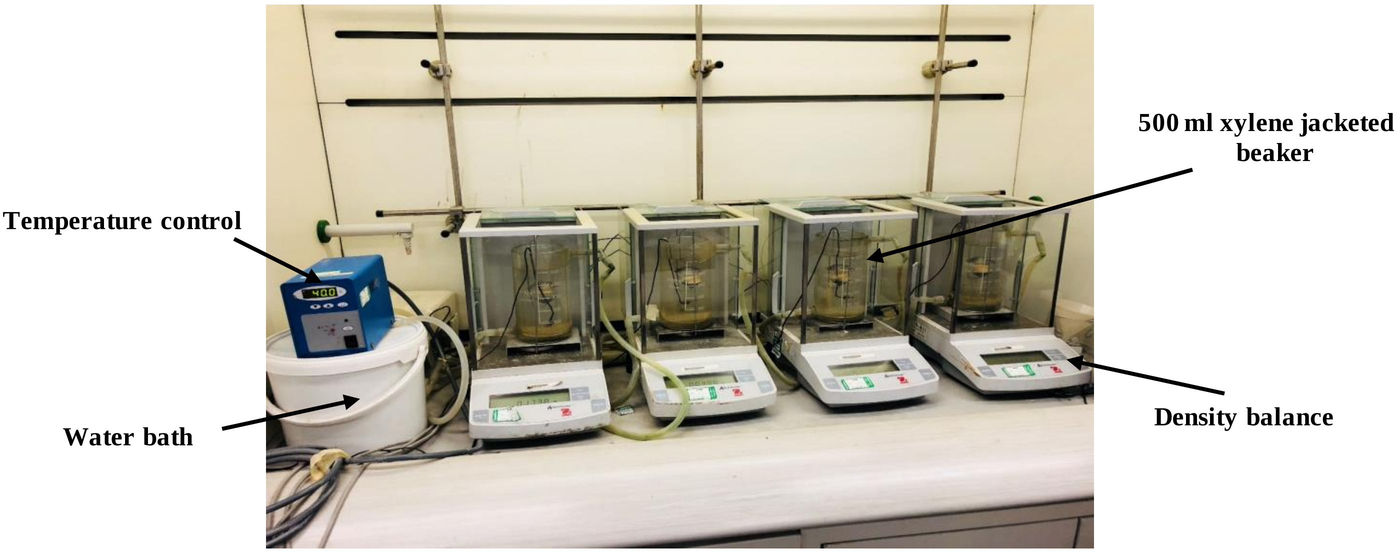


Figure 5.11 Dynamic Dough Density setup

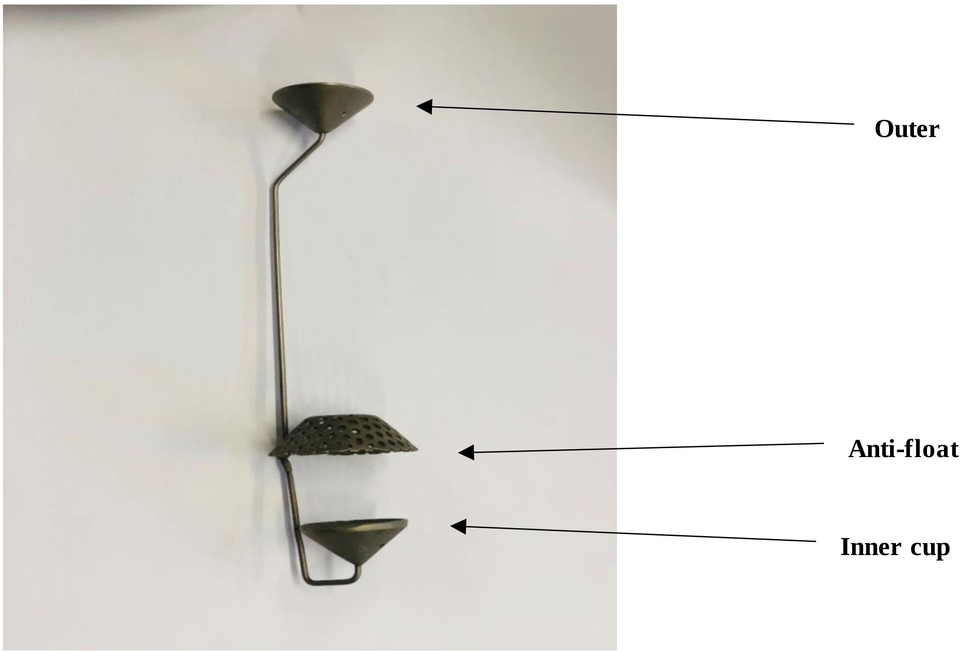


Figure 5.12 Double cup used in the DDD system.

5.3.4 Springback

The Dynamic Dough Density system quantifies dough development by measuring the maximum expansion of a dough piece under conditions that mimic proving. However, it was noticed that after sheeting at a certain roll gap, the dough relaxes to a larger final thickness than the roll gap through which it was passed. It was hypothesised that this "springback", defined as the ratio of the dough thickness to the roll gap, might also indicate the extent of gluten development, and that it might therefore be correlated with DDD expansion. If so, measurement of springback would be a more convenient way than DDD of quantifying the effect of sheeting on dough development.

Immediately after sheeting for a set number of passes, four readings of springback were taken by inserting the Depth Gauge into the centre of the sheeted dough. The springback of the dough is calculated as following:

Springback of the dough = reading of Depth Gauge (mm)/ roll gap of sheeter (mm)

5.3.5 Baking Bread

Doughs were prepared using the same recipes as for the DDD experiments. Table 5.3 shows the experiment's design of baking bread. After mixing in the Tweedy mixer for three minutes, the doughs were sheeted through the manual sheeter at roll gap settings of 6, 9 and 12 mm. Between 2 and 12 sheeting passes were applied, along with a zero-pass sample that was the dough immediately from the mixer. For the investigation of the effect of the number of sheeting and different combinations of roll gap on the baked loaf quality, yeasted doughs were sheeted, then from each sheet four pieces were taken using the rectangular cutter as shown in Figures 5.13, which was used to cut out rectangular dough pieces with dimensions of 6 × 12 mm. Figure 5.14 shows the pieces of dough before and after proving and the final baked loaf. The samples were transferred to proving in an oven at 43°C for 45 minutes, then moved to a different oven for baking at 175°C for 27 minutes. The volume and texture of final baked loaves were measured by seed displacement, EinScan-SP 3D scanner, by texture analysis, and C-Cell colour system respectively, as described below.

Table 5.3 Experiment's design of baking bread

Dough formulation	Roll gap (mm)	Number of sheeting	Number of doughs	Number of samples	Factors investigated
Without bran	6,9,12	0,3,6,9,12	15	60 180*	- Rapeseed displacement (Volume of bread) -Texture analyser (Firmness of bread)
With 10% bran (3 bran particle sizes plus a Control)	6,12	4,8,12	24	96 288**	- 3D scanner (Volume of bread) -C-Cell tests (crumb cell structure)

*(4 sheeting passes plus a Control × 3 roll gaps × 4 loaves = 60 loaves baked× 3 slices= 180 slices are investigated by Texture analyser)

**(3 bran particle sizes plus a Control × 3 sheeting passes × 2 roll gaps × 4 loaves = 96 loaves baked× 3 slices= 288 slices are investigated by C-Cell)

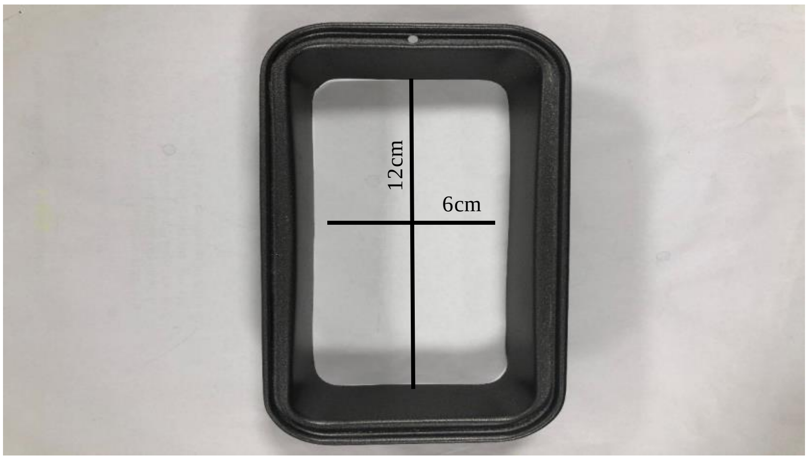


Figure 5.13 Rectangular cutter.

Figure 5.14 Approximately 100 g sheeted dough pieces (left) , after proving (middle) and after baking (right).

5.3.6 Measurement of specific volume of bread

5.3.6.1 *Rapeseed displacement*

The specific volume of loaves was calculated according to the AACC method 10-05.01 by dividing volume (cc) by weight (g) (AACC 2011). Bread volume was measured using rapeseed by displacing these seeds on the second day after removal from the oven and weighing. After that, the loaves were placed in a container of known volume into which rapeseeds were run until the container was full. The loaf volume is given by the volume of seeds displaced. Specific volume was calculated as cm^3/g by dividing the volume of the bread loaf by its weight as:

$$LSV = \text{Loaf volume } (cm^3) / \text{Loaf weight } (g) = cm^3/g$$

5.3.6.2 *3D scanning of loaf volume*

The EinScan-SP structured-light 3D scanner is a 3D scanning device for measuring the three-dimensional shape of an object using projected light patterns and a camera system (Shining3D, 2019, July 14). Its working principle is to project a narrow beam of light onto a three-dimensional object, distorting the shape of straight lines from a different perspective than the projector, from which the precise geometry of the body surface can be calculated. Models of light are commonly used in the form of parallel lines.

Calibration is the first step in the operation of the 3D scanner to compensate for the geometric distortions that occur by optics and perspective. Calibration is done by the special calibration patterns and surfaces (Calibration board kit) as shown in Figure

5.15(a). After calibration is complete, the loaf of bread is placed in the sample area on the turntable as shown in Figure 5.15(b). The model or status in the software which was chosen for scanning the final baked bread samples was as follows:

Device type: EinScan-SP
Scan Mode: Fixed Scan
Texture: Non-texture (non-colour picture) and Texture Scan (Coloured picture) White Light Auto Scan (White balance test) just if Texture Scan is Chosen
Shade type: Medium
Turntable Steps: 8 steps (non-colour picture) and 25 steps (Coloured picture)

The Meshmixer program was used to calculate the volume of final baked loaves (cc) by upload the 3D pictures of loaves after that their weights (g) are entered manually to get the specific volume of bread. Specific volume was calculated as cm^3/g by dividing the volume of the bread loaf by its weight (Meshmixer, 2018).

Figure 5.15 EinScan-SP 3-D scanner, calibration (a), sample test (b).

5.3.7 Determination of firmness of bread

Hardness tests were performed on an individual loaf one slice at a time, following the AACC 74-09 standard method for determination of bread firmness. The slices were taken by slicing the final loaf by hand into four equal pieces of thickness each of 25 mm thick. After the probe touched the sample, the maximum force required to compress the bread by a pre-set distance of 10 mm was recorded and compared between the samples.

The TA-XT2 Settings used were:

Mode	Measure Force in Compression
Option	Return to Start
Pre-Test Speed	1.0 mm/s
Test Speed	1.7 mm/s
Post-Test Speed	10.0 mm/s
Strain	40 per cent

Trigger Type	Auto 5 g
Data Acquisition Rate	250 pps (Pulse-per-second)
Probe	36 mm cylinder probe with radius (P/36R) using 5 kg load cell

Firstly, it was verified that the probe was not inclined to cut the sample as it penetrated by rounding the edges of the cylinder to remove the sharpness of the perimeter of the probe. The bread loaf was sliced into equal slice thickness of 25 mm using a knife. The probe was calibrated by doing the test using '% strain' measurement. The probe was lowered to be close to the test surface. On the menu bar of the Texture Analyser, the icon for Calibrating Probe was clicked and the distance of 30 mm specified for the probe to return to after sample compression. Before starting the tests, the auto height box was checked inside the 'Run a Test' window. The sample was placed centrally under the cylinder probe in order to avoid any irregular or unrepresentative areas of the crumb, and the test was started. Once the trigger force was reached, the probe continued to compress the sample until it reached 40 per cent of the original height, i.e. 10 mm. It then returned to its starting position after withdrawing from the sample. The outcomes were presented in Texture Expert Exceed plots, from which the hardness was reported as shown in the Figure 5.16. The data were analysed and obtained automatically by a built-in macro.

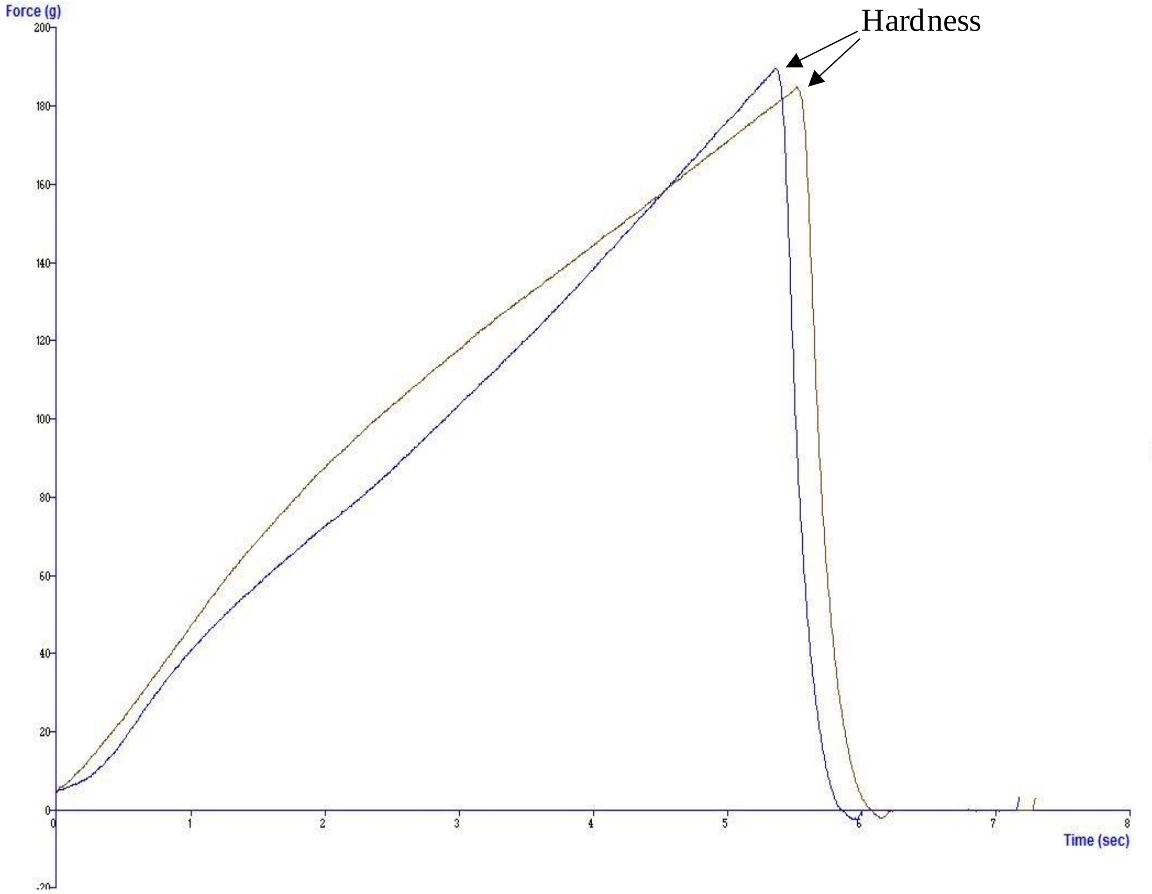
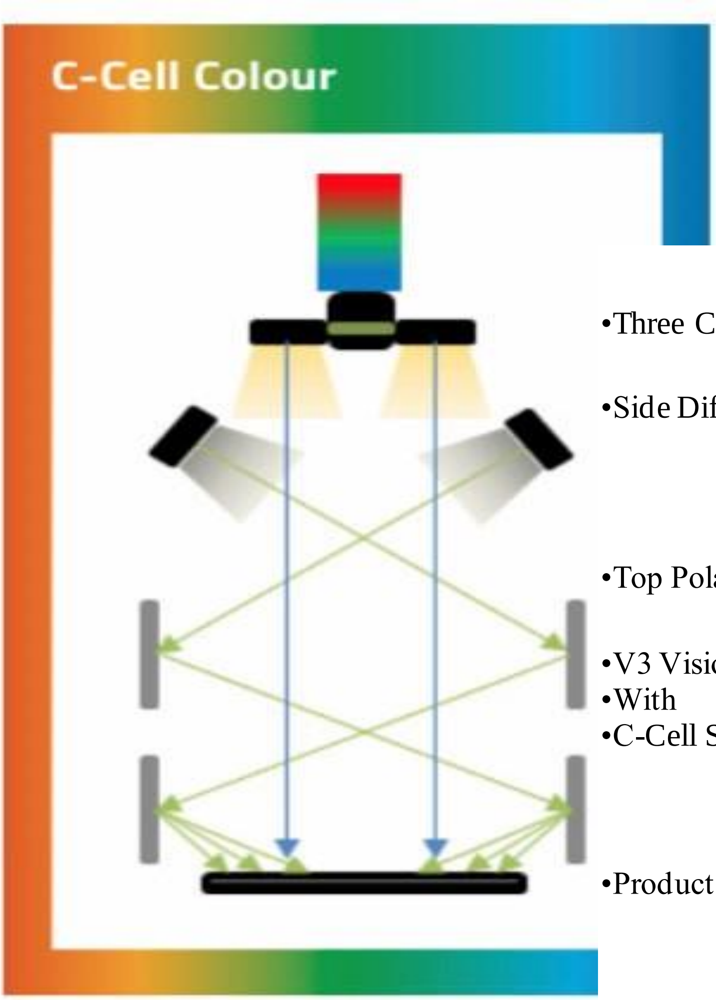


Figure 5.16 Force profiles and hardness measurement of two bread slices (25 mm thick) from same sample.

5.3.8 C-Cell Colour analysis

Figure 5.17 illustrates how the C-Cell uses low angle lighting to illuminate the surface of a slice of bread, giving good contrast and allowing cell structure to be clearly seen and analysed. Figure 5.18 shows the five images with which the system can display the features of a slice of bread. The C-Cell Colour analyses these images and provides over 50 data values that describe certain features and characteristics of the slice, including the number of cells, their circulation, cell elongation, average diameter and wall thickness, as well as overall shape and size information and identification of faults such as large holes or abnormally large cells. For the purposes of the current study, the most important data were number of cells, average cell diameter and wall thickness. A well-developed dough should retain gas and resist bubble coalescence during proving and baking, leading to a large number of small diameter gas cells with thin cell walls. As sheeting develops gluten structure efficiently, it was anticipated that effects of sheeting and bran particles on gluten development would be reflected in the size and number of gas cells in the loaf and the thicknesses of the gas cell walls.

Calibration is the most important and first step to be taken in the operation of the C-Cell. Calibration is done using a board kit that is attached to the C-Cell. Final baked loaf samples were cut into slices of 12 mm thickness with a bread slicer (showing in Figure 5.19). The central four slices were used for the analysis to evaluate crumb structure. The slices of bread crumb were placed into C-Cell in the place designated for the samples as showing in Figure 5.20. Then follow the steps to take images of the bread slices and the data is automatically collected and saved by the software. In this study, from the 50 data values evaluated for the structural properties of the bread crumb, the number of cells, mean cell diameter and cell wall thickness were selected as the most important parameters for this study.



- Three Chip Colour Camera
- Side Diffuse and Polarised Light
- Top Polarised Light
- V3 Vision Analysis Software
- With
- C-Cell Structure Analysis
- Product Colour Measurements

Figure 5.17 Illustration of C-CELL imaging process and the 5 images (Chopin, 2012).

Raw image

- Calibrated, unprocessed image

Brightness

- Adjusted to constant brightness.

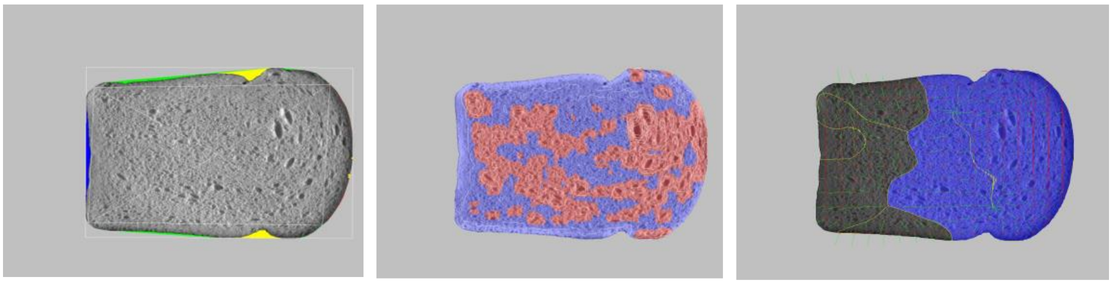
- Helps viewing of structure in dark images

Cells

- Shows cells detected.

- Colour coded by volume.

- Holes circled in red.



Shape

- Dimensions shown as box.

- Concave regions and break shown in colour.

Volume map

- Coarse regions shaded red.

- Fine regions shaded blue.

Elongatio

- Red lines show orientation.

- Green lines show curvature.

- Circulating structures shaded blue.

Figure 5.18 Illustration the 5 images of C-CELL (Chopin, 2012)

Figure 5.19 The bread slicer.

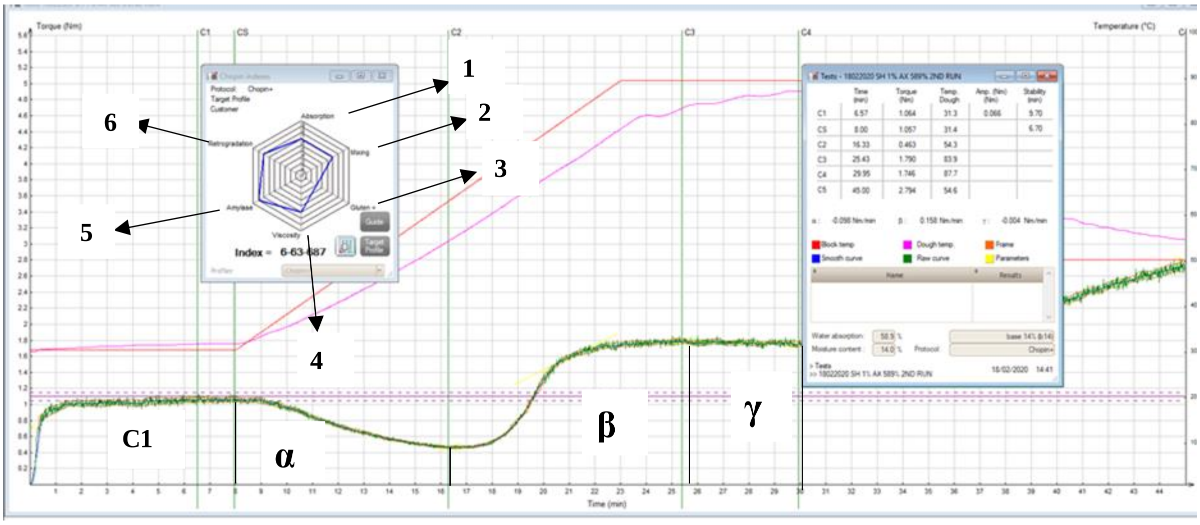
Figure 5.20 Slice of bread placed in C-Cell sample chamber.

5.3.9 Measurement of water absorption

The Mixolab 2 by CHOPIN Technologies is designed for characterizing the rheological behaviour of dough subjected to a dual mixing and temperature constraint (Chopin, 2012). It measures torque (expressed in N m) produced by the dough between the two mixing blades in real time, allowing the study of rheological and enzymatic parameters such as dough rheological characteristics (hydration capacity, development time, etc.) as well as the protein weakening, enzymatic activity, starch gelatinization and retrogradation (Chopin, 2012). The Mixolab 2 allows creation of customized testing protocols for white or whole wheat flours or doughs sampled directly online.

The Mixolab 2 works with a constant dough weight of 75 g. This requires some iteration to work out the water absorption, so that the final weight of flour plus water exactly equals 75 g.

Figure 5.21 shows a typical Mixolab 2 torque curve and temperature profile. The Mixolab Profiler translates the standard curve into 6 summary indicators or parameters, calculated from combinations of features of the curve, and shown as the spider diagram within Figure 5.21. The characteristics of flour can be classified and determined on these six basic criteria:



Tests - 18022020 SH 1% AX 589% 2ND RUN

	Time (min)	Torque (Nm)	Temp. Dough	Amp. (Nm) (Nm)	Stability (min)
C1	6.57	1.064	31.3	0.066	9.70
CS	8.00	1.057	31.4		6.70
C2	16.33	0.463	54.3		
C3	25.43	1.790	83.9		
C4	29.95	1.746	87.7		
C5	45.00	2.794	54.6		

α : -0.098 Nm/min β : 0.158 Nm/min γ : -0.004 Nm/min

🟥 Block temp 🟪 Dough temp 🟧 Frame
🟦 Smooth curve 🟩 Raw curve 🟨 Parameters

Name	Results

Water absorption : 58.5 % base 14% (b14)
Moisture content : 14.0 % Protocol Chopin+

> Tests
>> 18022020 SH 1% AX 589% 2ND RUN 18/02/2020 14:41

Figure 5.21 Results screen (example for a six indexes)

1- Water Absorption capacity:

Absorption potential depends on the flour composition (protein, starch, fibre, etc.), and affects dough yield. The higher the index, the more water is absorbed by the flour.

2- Mixing characteristic or Mixing Index:

The Mixing Index is calculated from the stability, dough development time (C1), weakening, etc. The higher the index, the greater the stability of the flour during mixing.

3- Gluten strength or Gluten Index:

This describes the properties of the gluten during the heating phase of the dough. The higher the index, the higher the resistance of the gluten to heating.

4- Maximum viscosity or Viscosity Index:

This describes the rise in viscosity throughout the heating stage as the starch gelatinises and the gluten denatures. The amylase activity and the starch quality are two important factors for this phase. The higher the index, the higher the viscosity of the dough when hot.

5- Amylase activity or Amylase Index:

This stage depends on the extent of resistance to amylolysis by starch. The higher the index, the lower the amylase activity.

6- Retrogradation or Retrogradation Index:

With the onset of cooling, starch retrogradation occurs and this increases the viscosity of the dough. Sometimes additives delay this phenomenon and give a softer final product. The Retrogradation Index depends on the properties of starch and its hydrolysis during the test. The higher the index, the shorter the product shelf-life. If starch retrogradation is rapid, the product is likely to stale more quickly, leading to a shorter shelf life.

- (α) Protein reduction

Increasing the dough temperature decreases consistency. The severity of the decrease gives an indication of protein quality.

- (β) Starch gelatinization

From a certain temperature, all phenomena that have a relationship to gelatinization of starch become dominant and an increase in consistency is observed. The intensity of the increase depends on two important factors, quality of the starch and on the additives in some cases.

- (γ) Amylase activity

The consistency value at the end of the plateau depends on the endogenous or added amylase activity. As the amylase activity increases, the greater the consistency decrease.

The above descriptions indicate the basis and meaning of the six indices, which are designed to allow simple summary comparisons of flours in the commercial context. However, in the current work interpretations were made based on the raw data rather than using these summary indices.

Preparing the test

In the "MIXOLAB CHOPIN Technologies" program, click on icon (Prepare a test).

A new window appears – choose the selection as follows:

Protocol: Chopin+ which is represented by the following:

- mixing speed, 80 rpm
- Water temperature, 30°C
- Block temperature, 30°C (1st plateau)

- Target torque, 1.1 N m
- Dough weight, 75 g
- Time, 45 min

Hydration base: 14%

Water content of sample used: 14%

The water absorption of the flour samples with bran was measured at 5, 10 and 15% bran (Coarse, Medium and Fine) with a control sample without bran. Water absorption required depends on the sample composition, it can be estimated initially based on the water absorption previously used in Section 5.3.2 (Table 5.2) then the Mixolab 2 automatically calculates the flour weight to be prepared (strong white flour was used) and the quantity of water that will be injected. Weigh the flour to ± 0.1g as per the weight that is indicated by the "CHOPIN MIXOLAB" software. The program suggests (pop-up) to the user to carry out another test with an adapted hydration that will be at t = 8 min, if the target torque (1.1 N m) has not been reached (this occurs only when using the Chopin+ protocol, valid only for a wheat flour). After 8 minutes, if the target torque of 1.1 N m is reached, the Mixolab 2 continues to measure the rest of parameters for 45 min, after which the results are presented as shown in Figure 5.21 and can be transferred into an Excel spreadsheet for further analysis.

5.4 Summary

A range of investigations were performed to investigate the effects of sheeting and bran incorporation on dough development and baked loaf quality. Doughs were mixed with and without bran, at different levels and particle sizes, and their ability to retain gas measured using springback after sheeting and maximum expansion in the Dynamic Dough Density system. Baked loaves were prepared, and their volumes measured by seed displacement or by more sophisticated 3D scanning and image analysis, while crumb structure was quantified using C-Cell image analysis. Later in the project a Chopin Mixolab became available, which was used to investigate in more detail the effects of bran particle size and level on water absorption and on behaviour of the dough during heating. The following chapters go systematically through these studies.

Chapter 6. Effect of sheeting on white flour doughs

6.1 Introduction

This chapter presents the results of investigations into the effects of sheeting of doughs mixed in two different mixers (MajorPin mixer, Tweedy 1 mixer) without bran plus preliminary studies with bran. Doughs were mixed at different times in the Tweedy mixer and the MajorPin mixer and further developed by sheeting. The aeration of the dough, as indicated by the density, and the development of the dough's gluten structure, as indicated by the maximum expansion capacity of the dough measured using the Dynamic Dough Density test, and the quality of the bread, as indicated by the volume of the final baked loaf and the texture analyser, were investigated.

6.2 Investigations using the MajorPin mixer

This section describes a series of investigations to measure the effects of sheeting on doughs mixed in the slow speed MajorPin mixer, to compare the extent of development achieved through mixing with that achieved through sheeting, as measured by the DDD system.

Dough samples were prepared in the MajorPin mixer as described in Chapter 5, with or without yeast according to the formulation in Table 6.1.

Table 6.1 Ingredients and their quantities used for dough formulation.

Ingredients	Quantity (g)
Strong white flour	400
Fat	20
Salt	6.4
Water	244
yeast*	16

* Yeast was omitted for static dough density tests.

6.2.1 Effect of the number of sheeting passes on unyeasted dough aeration

The effect of sheeting on aeration of unyeasted doughs was examined, in order to understand the effect of sheeting on degassing of doughs and on entrainment of air. Doughs were prepared by mixing all ingredients (flour, salt, fat, water) for five minutes in the MajorPin mixer. Immediately after mixing, the doughs were sheeted through the manual sheeter at a roll gap setting of 12 mm. After each sheeting pass the elongated dough piece was folded and turned before the next sheeting pass. Between 2 and 12 sheeting passes were applied, in a random order, along with a zero pass sample that was the dough immediately from the mixer. The experiment was then repeated using the reverse random order. After each sheeting pass, six samples were collected from the sheeted dough, using a 21 mm circular cutter to produce a cylinder of dough. The density of all six samples was measured in the density meter and averaged.

6.2.2 Effects of roll gap and number of sheeting passes on yeasted dough development using MajorPin mixer

For the investigation of the effect of sheeting on dough development, yeasted doughs were prepared in the MajorPin mixer and sheeted at gaps of 6 and 12 mm for between 2 and 12 passes, in a random order, and repeated in the reverse random order. From each sheet four samples were taken using the 21 mm circular cutter. These samples were swirled for several seconds in a spherical flask, to strengthen the edges in order to avoid unrepresentative gas loss from weakened edges (Campbell et al., 2008a). The samples were transferred to the four DDD systems; their weights in air were recorded, then the samples were immersed in the xylene and their changing weights monitored and recorded every 10 seconds for up to 1 hour. Careful attention was paid to sample handling and to the timing of the start of recording of the DDD test; the recording of DDD profiles was commenced exactly five minutes after the end of mixing. This was to ensure that the timescale for yeast activity was identical, despite different numbers of sheeting passes taking different amounts of time to achieve. Again, up to 12 sheeting passes were undertaken in a random order, then repeated in a reverse random order. Thus for each sheeting pass, eight samples were put through the DDD test, and the minimum density achieved by the growing dough piece measured.

The experiment was repeated with including a new roll gap, 9 mm. Doughs were mixed in the MajorPin mixer as described above. Immediately after mixing, the doughs were sheeted through the manual sheeter at roll gaps of 6, 9 and 12 mm. After the final sheeting at 6 and 9 mm, the elongated dough piece was folded and passed through a 12 mm gap to get the same thickness of all samples. Between 2 and 12 sheeting passes were applied, in a random order, along with a zero pass sample that was the dough immediately from the mixer.

6.3 Investigations using the Tweedy 1 Mixer

Mechanical dough development using high speed mixing is more effective at developing the gluten network, compared with slower speed mixing as in the Majorpin mixer. In this section an investigation into development in the high speed Tweedy 1 mixer followed by sheeting is presented.

Doughs with or without yeast were prepared by mixing all ingredients using the Tweedy 1 mixer using the same formulation as given above in Table 6.1. The DDD system was used to measure the extent of development achieved through mixing with that achieved through sheeting.

6.3.1 Effects of the number of sheeting passes on unyeasted dough aeration

For the investigation of the effect of sheeting on aeration of unyeasted doughs, doughs were prepared by mixing all ingredients as described in Section 6.2.1.2.1. After each sheeting pass, six samples were collected from the sheeted dough, using a 21 mm circular cutter to produce a cylinder of dough. The density of all six samples was measured in the density meter and averaged.

6.3.2 Effects of mixing time and number of sheeting passes on yeasted dough development using Tweedy 1 mixer

The doughs were prepared by mixing all ingredients (flour, salt, fat, water, sugar and yeast) for different times (1, 2, 3, 4 minutes) in the Tweedy 1 mixer. As high speed mixing in the Tweedy mixer imparts a lot of energy which heats the dough, the same final dough temperature was targeted by adjusting the temperature of the water used in the mixing depending on the mixing time. The experiments were done separately on different days. In the first experiment, doughs were mixed for 1, 2, 3 and 4 minutes, then 0, 1, 2 and 3 sheeting passes applied. In the second experiment, doughs were again mixed for 1, 2, 3 and 4 minutes, then a wider range of sheeting passes, 0, 2, 4 and 6, were applied. Immediately after mixing, the doughs were sheeted through the manual sheeter at a roll gap setting of 6 mm. After each sheeting pass, the elongated dough piece was folded and turned before the next sheeting pass. After the final sheeting, the elongated dough piece was folded and passed through a 12 mm gap to get a consistent thickness for DDD sampling. Between 1 and 6 sheeting passes were applied, in a random order, along with a zero pass sample that was the dough immediately from the mixer.

As above, from each sheet four samples were taken using the 21 mm circular cutter, swirled in a spherical flask and transferred to the four DDD systems, with the recording of DDD profiles commencing exactly six minutes after the end of mixing.

6.3.3 Effects of the number of sheeting passes on baked loaf quality

Doughs were prepared using the same recipe as for the DDD experiments and loaves baked as described in Section 5.3.2. The volume and the texture of final baked loaves were measured by seed displacement and by texture analysis, as described in Sections 5.3.6.1 and 5.3.7.

6.4 Comparison of yeasted dough development using MajorPin mixer, Tweedy 1 mixer and Sheeter

The purpose of this investigation was to compare the extent of development of doughs, as indicated by the DDD test, in the MajorPin and Tweedy mixers and following sheeting. Broadly speaking, the Tweedy mixer imparts energy at a rate about five times that of the MajorPin mixer; hence doughs were mixed in the latter for five times as long as in the Tweedy mixer, in order to give a broad basis of comparability. In addition, minimally developed doughs (from 5 minutes' mixing in the MajorPin mixer) were further developed by sheeting.

Doughs were prepared by mixing for 5, 10, 15 and 20 minutes in the MajorPin mixer and for 1, 2, 3 and 4 minutes in the Tweedy mixer. In order to give comparable periods of yeast activity for the doughs mixed in the MajorPin mixer, the yeast was added only for the last 5 minutes of mixing when mixing the doughs for 10, 15 and 20 minutes. In the case of the Tweedy mixer, the timescales are much shorter such that variations in yeast activity in the mixer were of less concern, given the slow activity at lower temperatures relative to the activity when the sample is heated to 38°C for the DDD test. However, due to the high mechanical energy input, the temperature rises substantially during dough mixing. The final temperature was therefore controlled to a target of 30±1°C, by adjusting the initial water temperature. Appendix A describes the energy balance calculations used to determine the required initial water temperature to achieve a constant dough temperature at different mixing times.

In addition, doughs (with yeast) were mixed for 5 minutes in the MajorPin mixer, then sheeted through the manual sheeter at a roll gap setting of 6 mm, for 3, 6, 9 and 12 passes. After the final sheeting pass, the elongated dough piece was folded and passed a final time at a gap of 12 mm to get the same thickness of samples. The number of passes was applied in a random order, along with a zero pass sample that was the dough immediately from the mixer. The temperature at the end of the sheeting was recorded, as well as the time to undertake the sheeting regimes.

For doughs tested after mixing without sheeting, doughs were rolled once to a thickness of 12 mm, to give the same sample size as the doughs from sheeting. In all cases, four samples were taken using the 21 mm circular cutter and tested using the DDD system as described above. Careful attention was paid to sample handling and to the timing of the start of recording of the DDD test; the recording of DDD profiles was commenced exactly six minutes after the end of mixing. This was to ensure that the timescale for yeast activity was identical, despite a different time of mixing for each mixer and numbers of sheeting passes taking different amounts of time to achieve. Again, all the trials were undertaken in a random order.

6.5 Preliminary studies with bran using Tweedy 1 mixer

Doughs were prepared containing the ingredients listed in Table 5.1, with 10% bran particles (Coarse and Fine) and mixed in the Tweedy mixer for three minutes. 40 g of bran was added to the formulation of the dough, which replaced the same amount of flour, where the amount of flour was reduced from 400 g to 360 g. Immediately after mixing, the doughs were sheeted through the manual sheeter at the roll gap setting of 6 mm. After each sheeting pass the elongated dough piece was folded and turned before the next sheeting pass. After the final sheeting at 6 and 9 mm, the elongated dough piece was folded and passed through a 12 mm gap to get the same thickness of all samples. Between 2 and 12 sheeting passes were applied, in a random order, along with a zero pass sample that was the dough immediately from the mixer.

6.6 Results and discussion

This section presents the results of investigations into the effects of mixing and sheeting of doughs mixed with or without bran: on the aeration of the dough, as indicated by the density; on the development of the dough's gluten structure, as indicated by the maximum expansion capacity of the dough measured using the Dynamic Dough Density test; and on the quality of the bread, as indicated by the volume of the final baked loaf and the texture analyser. Doughs were mixed for different amounts of time in the Tweedy mixer and the MajorPin mixer and further developed by sheeting at different roll gaps and for different numbers of sheeting passes.

6.6.1 Investigations using the MajorPin mixer

6.6.1.1 *Effect of number of sheeting passes on unyeasted dough aeration*

Figure 6.1 shows the averaged density of unyeasted dough trials with different degrees of sheeting from 0 to 12 sheets. (The data are averaged from six samples taken from the same sheeted dough; error bars, based on ± 1 standard deviation, are not shown as they were smaller than the symbols used.) The trials were run in a random order on the first day and that order was reversed on the second day; the dough was prepared without yeast to monitor the extent of the density change with increasing the number of sheeting passes. Clearly, as the number of sheeting passes increases, the density increases significantly up to 9 sheets, after which a clear drop in density is evident. The initial increase in density indicates degassing of the dough. This agrees with Leong and Campbell (2008), who found that doughs were degassed following a single sheeting pass. However, the current work shows that this initial decline in gas content, leading to an observed increase in density, is then followed by a decrease in density after numerous sheeting passes. This could indicate that the by now highly degassed doughs start to entrain gas more quickly than it is removed, possibly as a result of the (over)developed rheology. It may also reflect a change in the gas-free density of the dough matrix as the gluten structure overdevelops. Chin et al. (2004) mixed doughs at different pressures to show that the gas-free dough density can vary as the dough develops. For sheeting studies, it is not possible to undertake the entire operation at different pressures in order to elucidate the effect on the structure and density of the gas-free; however, other approaches may be able to throw light on this possible effect.

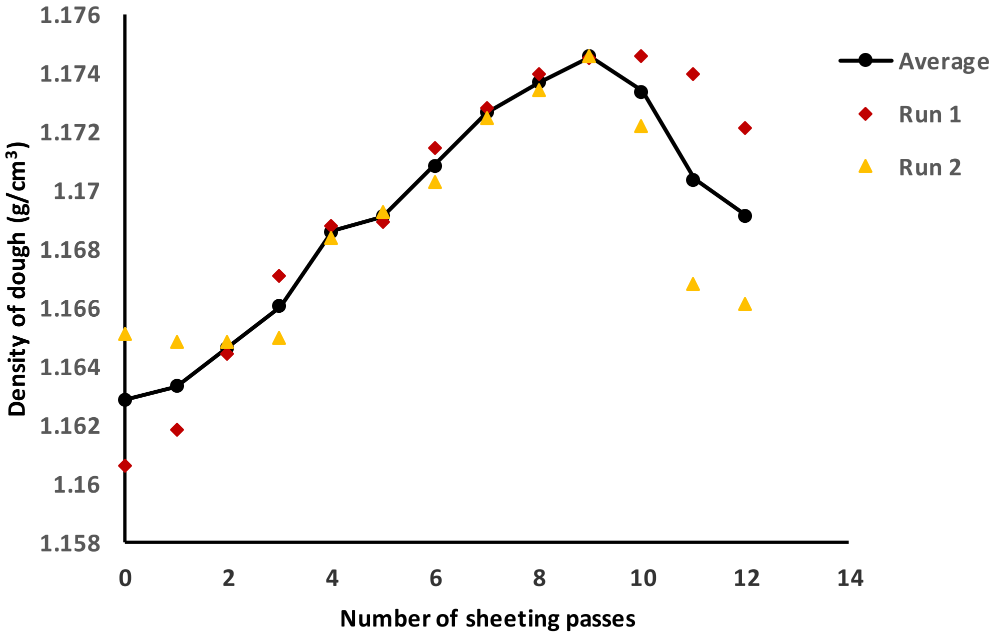


Figure 6.1 Averaged of random 1,2 for density of unyeasted dough against number of sheeting. (Error bars are not shown as they are smaller than the symbols used.)

6.6.1.2 *Effects of roll gap and number of sheeting passes on yeasted dough development*

Figure 6.2 illustrates the averaged density of yeasted dough profiles obtained from the dynamic dough density with different degrees of sheeting from 0 to 12 sheets at a roll gap of 12 mm. The trials were run in a random order on the first day and that order was reversed on the second day. Clearly, there is a decline in density at all degrees of sheeting until a minimum is reached, after which the expanded dough piece loses gas faster than it is produced, and the density increases. The minimum density indicates the expansion capacity of the dough. In the current work, as the number of sheeting passes increases, the minimum density decreases. This is more evident in Figure 6.3 which plots the minimum density of the eight replicate samples against number of sheeting passes, along with the average. Thus the minimum dough density following just mixing is around 0.395 g/cm^3, decreasing down to around 0.35 g/cm^3 after 12 sheeting passes. This gives clear evidence that sheeting has developed the dough and improved its ability to retain gas. If we assume a typical gas-free dough density of around 1.26 g/cm^3, this corresponds to an increase in gas voidage from about 68.7% up to 72.2%, enough to make a difference to the volume and texture of a baked loaf.

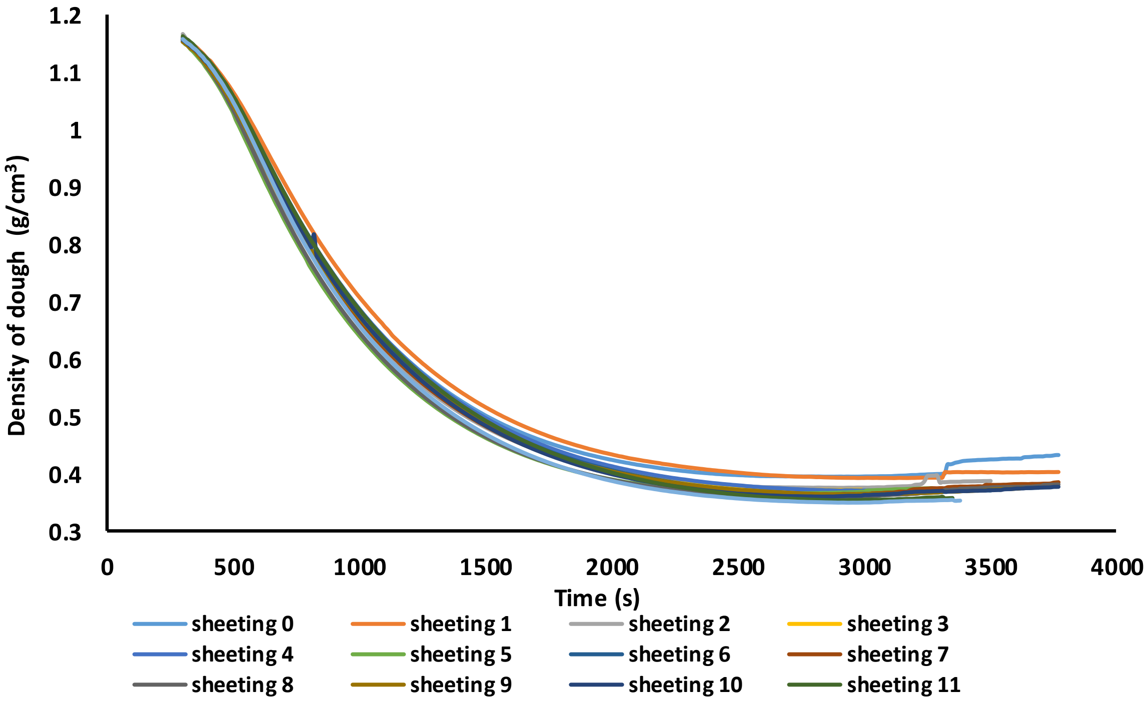


Figure 6.2 Dynamic Dough Density profiles for sheeted dough samples at a roll gap setting of 12 mm.

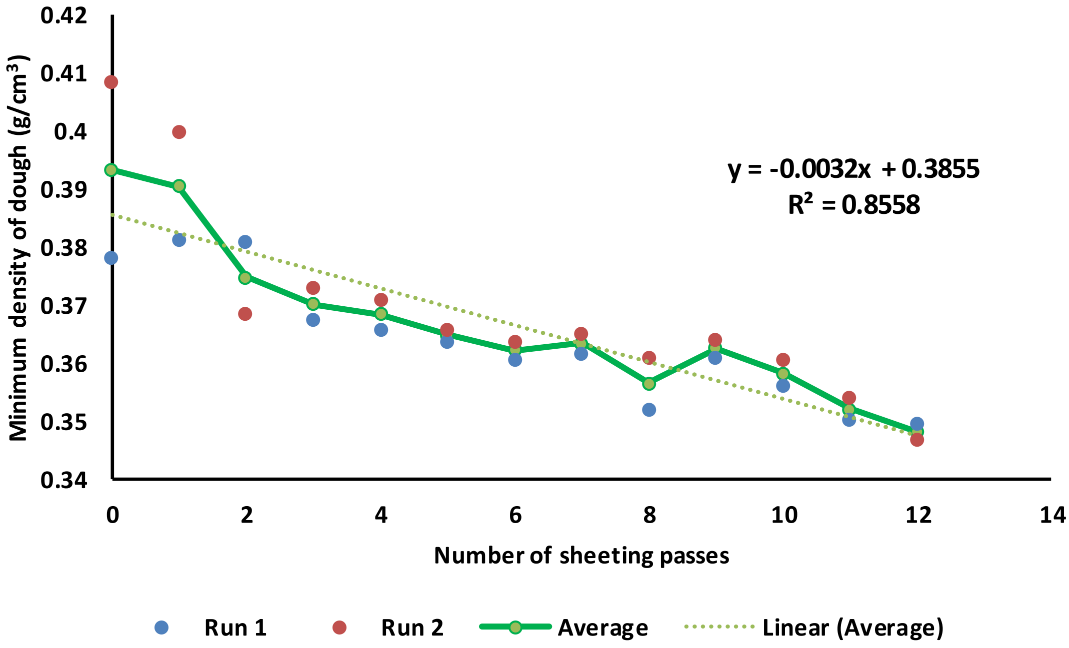


Figure 6.3 Averaged of random 1,2 minimum-yeasted dough density against number of sheets.

Figure 6.4 shows the time taken to reach the minimum density, for the different numbers of sheeting passes. Interestingly, although sheeting caused the expansion capacity of the dough to increase, this was not as a result of doughs expanding for longer; the effect of number of sheeting passes on the time to minimum density was insignificant. This gives clues regarding the effect of sheeting. If we make the reasonable assumption that the rate of CO_2 production by yeast is not affected by sheeting, then greater expansion could be achieved simply by the dough retaining gas for a little longer. The fact that greater expansion is achieved in the same time, irrespective of number of sheeting passes, suggests that although the yeast has produced the same amount of gas, more of it has partitioned into the gas phase and less of it has remained dissolved in the liquid phase of the dough. This would happen if there were a greater area for mass transfer of CO_2 from the liquid phase to the bubbles, which would arise from a greater number of smaller bubbles. Thus, the observation that the time to minimum does not change with number of sheeting passes suggests that sheeting has resulted in a population of smaller bubbles in the dough. Even through the total initial gas content of the dough decreases following sheeting (as indicated from the static dough density tests in Figure 6.1), the total combined surface area of those bubbles appears to have increased, suggesting that substantial break-up of bubbles occurs during sheeting, or that the bubbles entrained by sheeting are smaller than bubbles entrained during mixing. The sheeting process does not affect the time of proving process, and this may be unsuitable for bread manufacturing processes at the industrial and commercial levels.

Figures 6.4 and 6.5 plot the average minimum density and time to minimum on the same graph, along with error bars, based on ±1 standard deviation, based on a pooled standard deviation, calculated from the eight replicates.

Figure 6.6 gives more clarification for average Dynamic yeasted dough density profiles for doughs sheeted with 0, 6 and 12 passes.

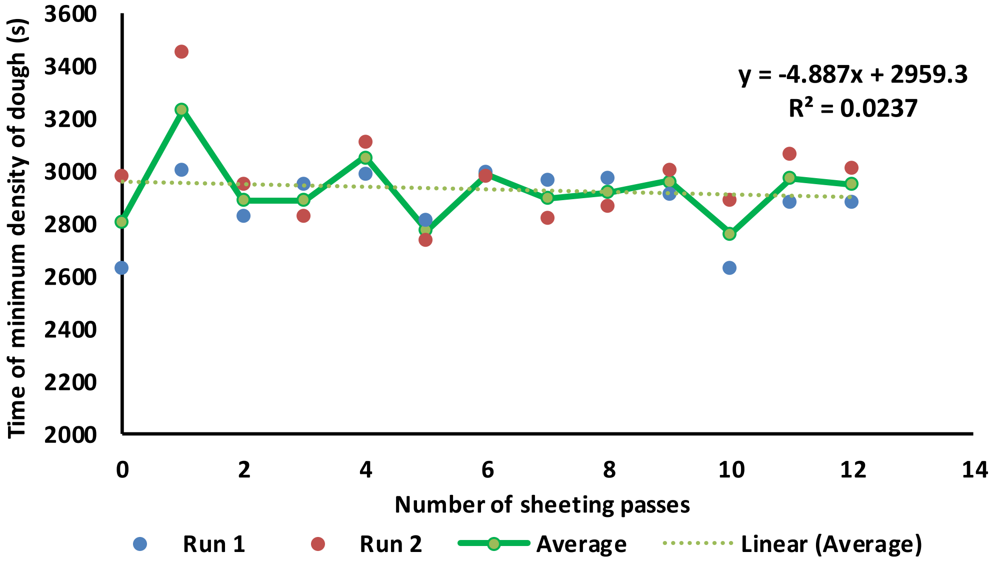


Figure 6.4 Averaged time of random 1,2 of the minimum-yeasted dough density against number of sheets.

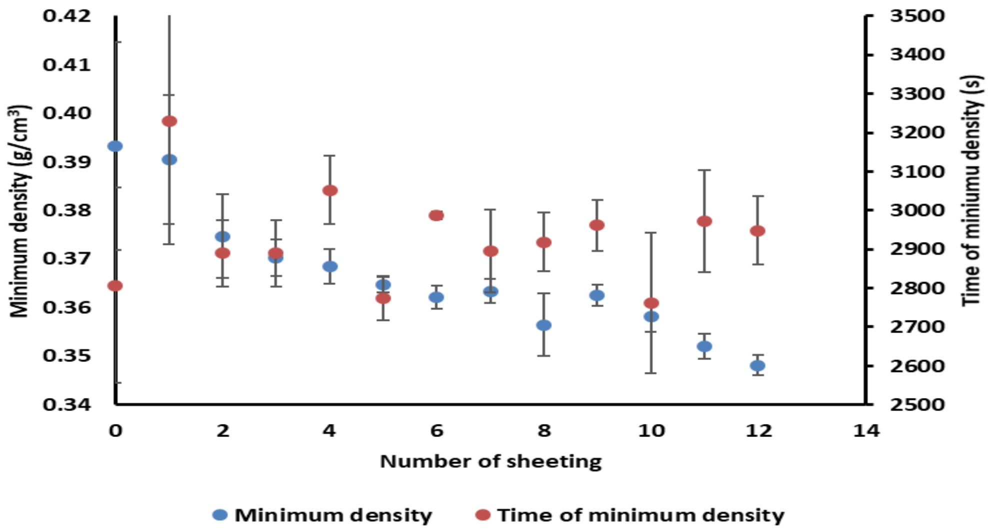


Figure 6.5 Averaged time and the minimum-yeasted dough density (Run 1,Run 2) against number of sheets.

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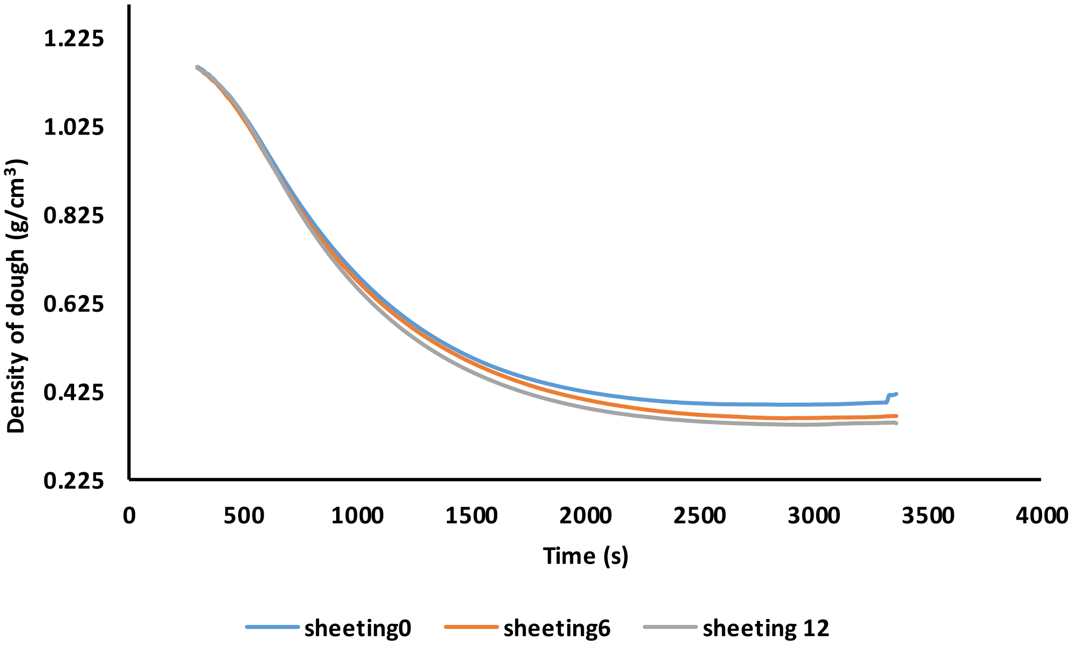


Figure 6.6 Average Dynamic Dough Density profiles for doughs sheeted with 0, 6 and 12 passes at a roll gap setting of 12 mm.

Figure 6.7 illustrates the average density of yeasted dough profiles obtained from the dynamic dough density with different degrees of sheeting from 0 to 12 sheets at a roll gap setting of 6mm after mixing for 5 minutes using the MajorPin mixer. Once again, there is a decline in density at all degrees of sheeting until a minimum is reached, after which the expanded dough piece loses gas faster than it is produced, and the density increases. This is more evident in Figure 6.8, which plots the minimum density of the eight replicate samples against number of sheeting passes, along with the average. For this set of trials using a 6 mm roll gap, the dough density ex-mixer is around 0.32 g/cm^3, decreasing down to around 0.28 g/cm^3 after 12 sheeting passes. This once again gives clear evidence that sheeting has developed the dough and improved its ability to retain gas.

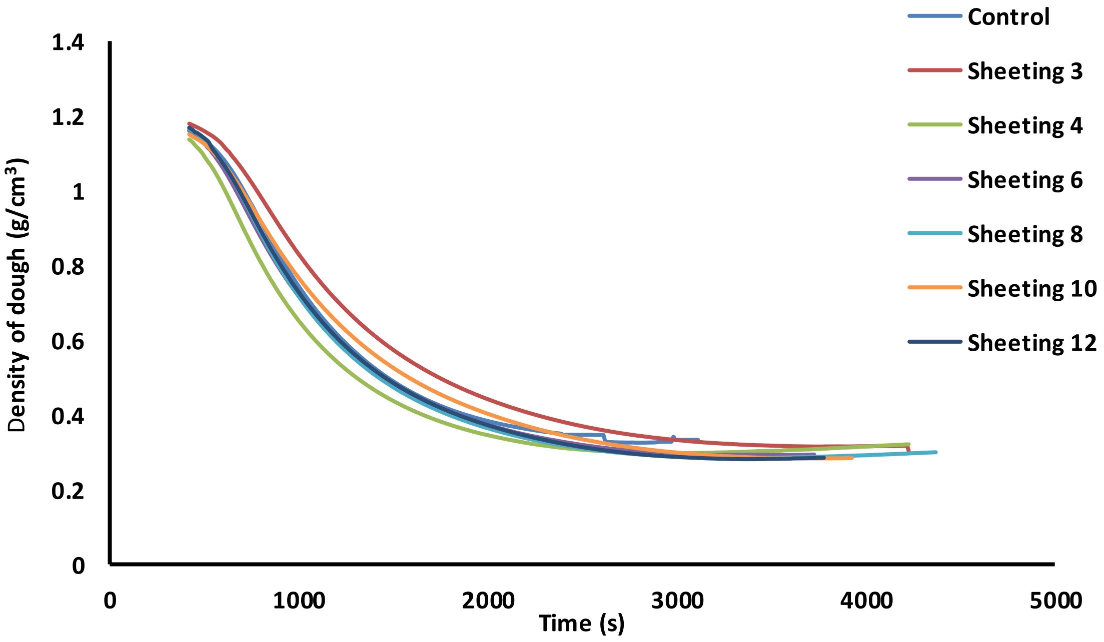


Figure 6.7 Average Dynamic yeasted dough density profiles for sheeted dough at a roll gap setting of 6mm.

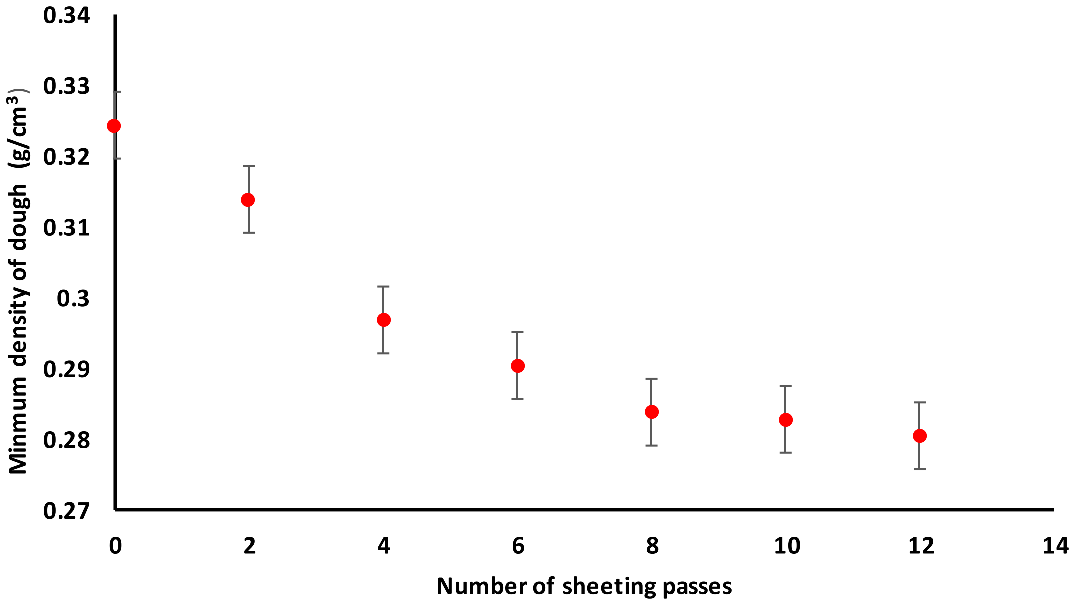


Figure 6.8 Averaged of minimum-yeasted dough density against number of sheets, at a roll gap setting of 6 mm and mixed for 5 minutes using Majorpin mixer.

Figure 6.9 shows the time taken to reach the minimum density, the observation that the time to a minimum does not change with the number of sheeting passes. Once again it indicates that the lower density (greater expansion) is not simply because the dough is retaining gas for longer. Rather, more gas is being transferred into bubbles rather than staying dissolved in the liquid phase of the dough. This implies a greater surface area for mass transfer, again suggesting that sheeting has resulted in a greater number of smaller bubbles.

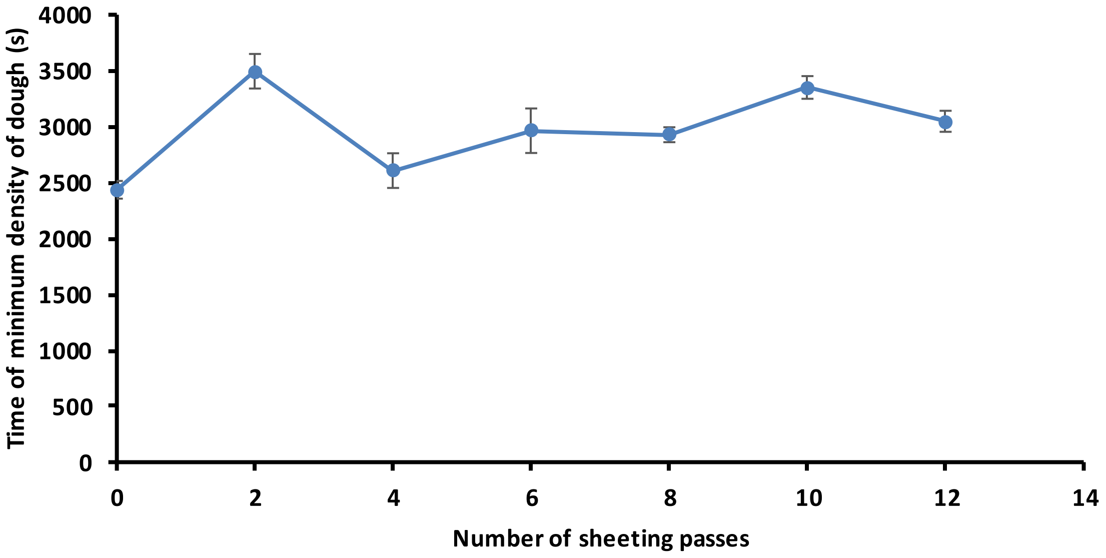


Figure 6.9 The time of the minimum-yeasted dough density against number of sheets.

Figure 6.10 illustrates the averaged minimum density of yeasted dough profiles obtained from the dynamic dough density with different degrees of sheeting 0, 3, 6, 9 and 12 sheets and at different roll gaps 6, 9 and 12 mm using MajorPin mixer. The trials were run in a random order. Again, there is a decline in the minimum density at all degrees of sheeting and with decreases the thickness of dough by using a smaller gap. In this case the dough density ex-mixer is around 0.35 g/cm^3, decreasing down to around 0.28, 0.29 and 0.30 g/cm^3 after 12 sheeting passes using rolls gaps 6, 9 and 12 mm respectively. This gives clear evidence that smaller roll gaps giving more efficient development.

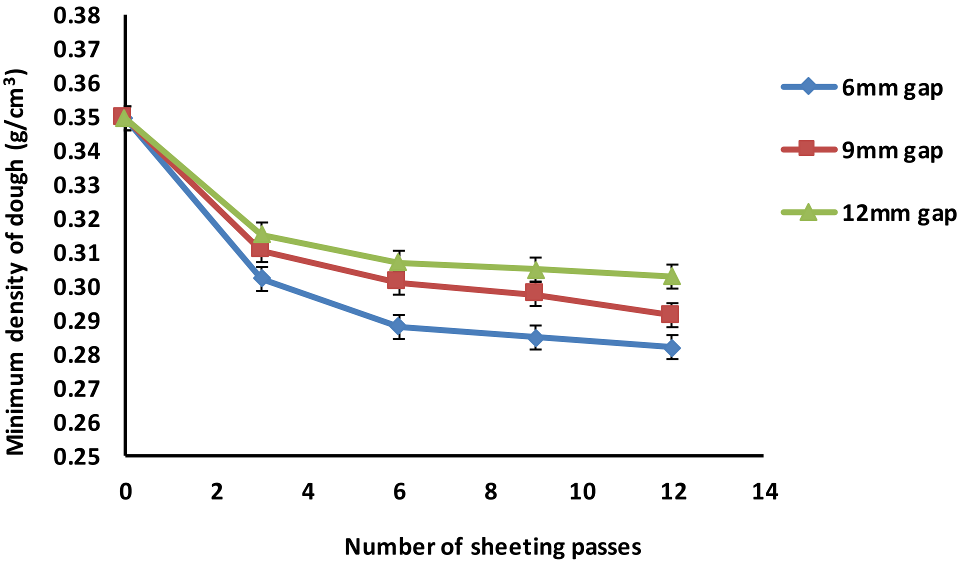


Figure 6.10 Minimum dough density against number of sheets (0, 3, 6, 9, 12) at a roll gaps setting of 6, 9 and 12 mm and mixed 5m using MajorPin mixer.

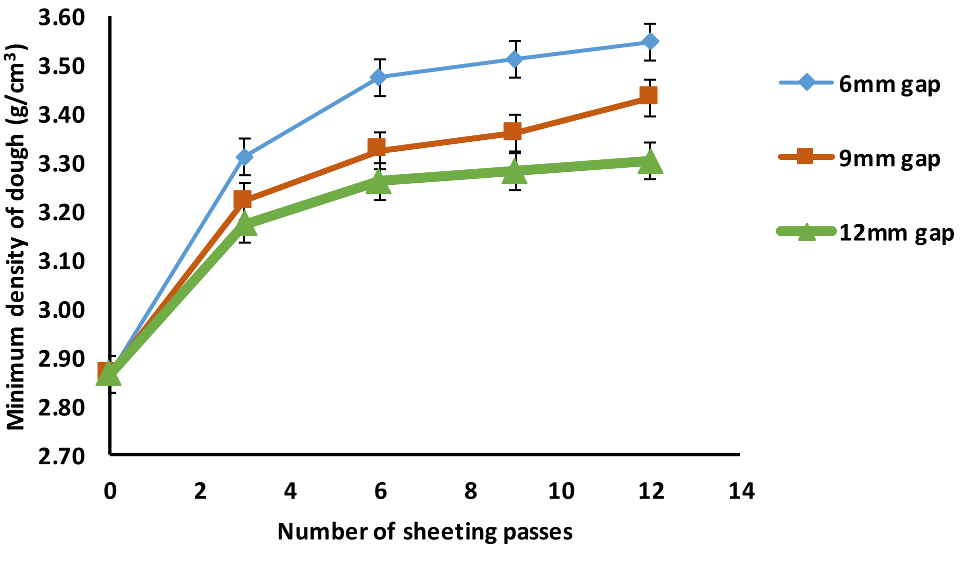


Figure 6.11 Minimum dough expansion against number of sheets (0, 3, 6, 9, 12) at a roll gaps setting of 6, 9 and 12 mm and mixed 5m using MajorPin mixer.

6.6.2 Investigations using Tweedy 1 mixer

6.6.2.1 *Effect of sheeting on static dough density*

Figure 6.12 shows the averaged density of unyeasted dough trials with different degrees of sheeting from 0 to 12 sheets at a roll gap setting of 6 mm and mixed for 3 minutes using the Tweedy 1 mixer. (The data are averaged from six samples taken from the same sheeted dough.) The trials were run in a random order on the first day and that order was reversed on the second day; the dough was prepared without yeast to monitor the extent of the density change with increasing the number of sheeting passes. Clearly, as the number of sheeting passes increases, the density increases significantly up to 8 passes, after which a clear drop in density is evident. This correspond to the previous results when using the Major Pin mixer but in previous results the density continued to increase to the 9 passes before dropping. This could indicate that when using the Tweedy mixer with sheeting the highly degassed doughs start to entrain gas more quickly than it is removed, possibly as a result of the (over)developed rheology resulting from the use of the Tweedy mixer with sheeting. It may also reflect a change in the gas-free density of the dough matrix as the gluten structure overdevelops when using the tweedy mixer compared to using Major Pin mixer.

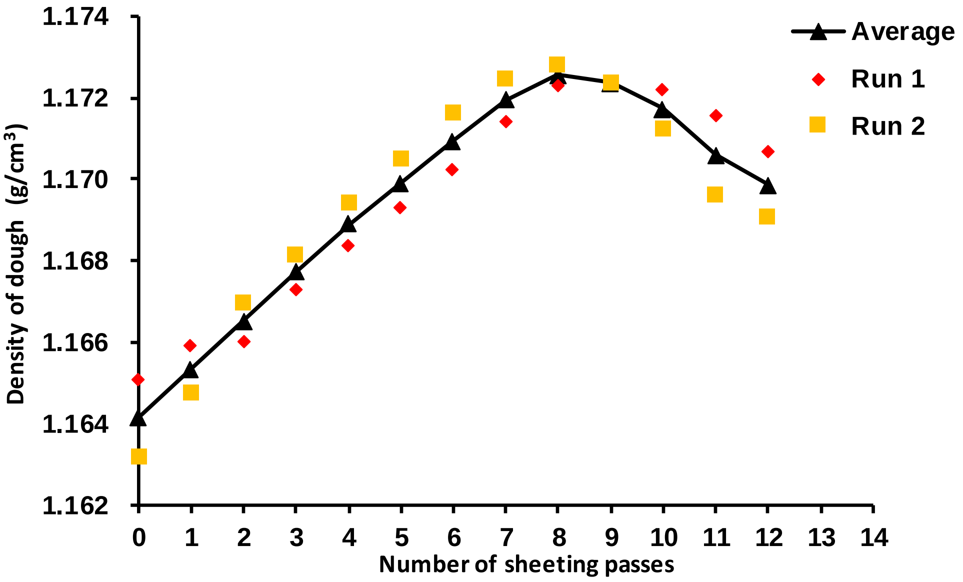


Figure 6.12 Average density of unyeasted dough against number of sheeting passes at a roll gap setting of 6 mm, for doughs mixed for 5 minutes in the Tweedy 1 mixer.

6.6.2.2 *Effects of the number of sheeting passes on dough development and aeration at different times of mixing using Tweedy mixer*

Figures 6.13 and 6.14 show the average minimum density of yeasted dough profiles obtained from the DDD system with different degrees of sheeting from 0 to 6 sheets following different mixing times (1, 2, 3 and 4 minutes) using the Tweedy 1 mixer. The experiments were done on different days so that the figures are shown separately; on each day, the trials were run in a random order.

In the first experiment, the number of sheeting passes varied from 0 to 3, for doughs mixed initially for different mixing times. Clearly, as mixing time increases from 1 minute to 4 minutes, there is a decrease in the minimum density, showing that mixing develops the ability of the dough to expand. Then, passing the mixed dough through the sheeter decreases the minimum density further, showing that sheeting increases further the dough development and its ability to expand and retain gas. Even when the dough is highly developed after 4 minutes of mixing, sheeting is able to develop the dough further. For a minimally mixed dough, the increase in expansion resulting from sheeting is greater than for a highly mixed dough; however, 1 minute of mixing followed by three sheeting passes is unable to deliver as much development as 4 minutes of mixing.

In the second experiment, the number of sheeting passes was increased to six. This showed that after 1 minute of mixing, sheeting increased the ability of dough to expand all the way up to six sheeting passes, but after 4 minutes of mixing, sheeting only developed the dough further for two passes, after which the dough failed to develop any further.

Clearly, both mixing and sheeting develop dough. Sheeting after minimal mixing (1 minute of mixing in the Tweedy 1) gave a greater increase than after longer mixing periods, but overall was less effective than mixing for longer. The greatest expansion capacity came from mixing for 4 minutes followed by two sheeting passes, while further sheeting gave no further increase in expansion capacity.

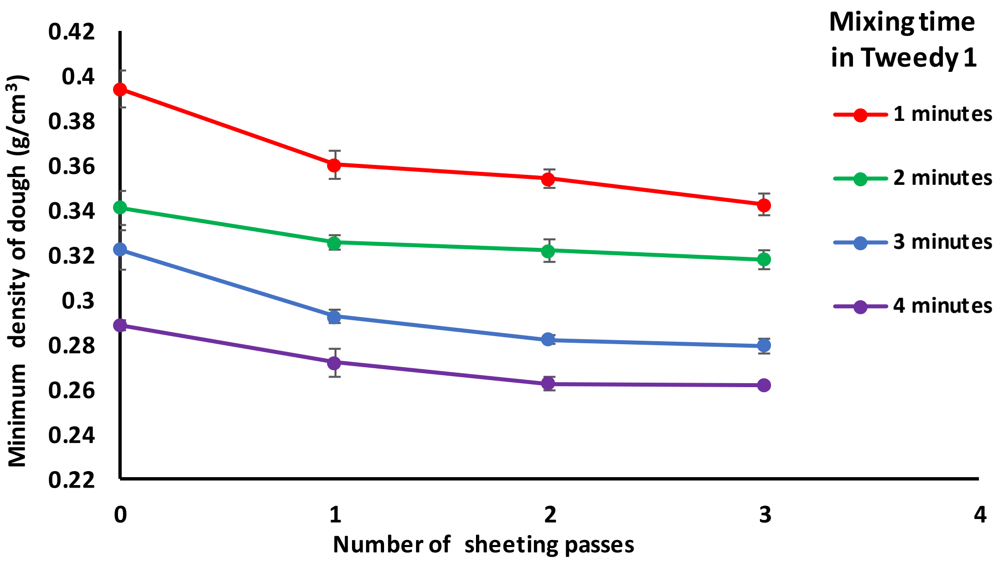


Figure 6.13 Averaged of minimum-yeasted dough density against number of sheets (0,1,2,3) at a roll gap setting of 6 mm and at different mixing times (1,2,3,4 minutes)using Tweedy mixer.

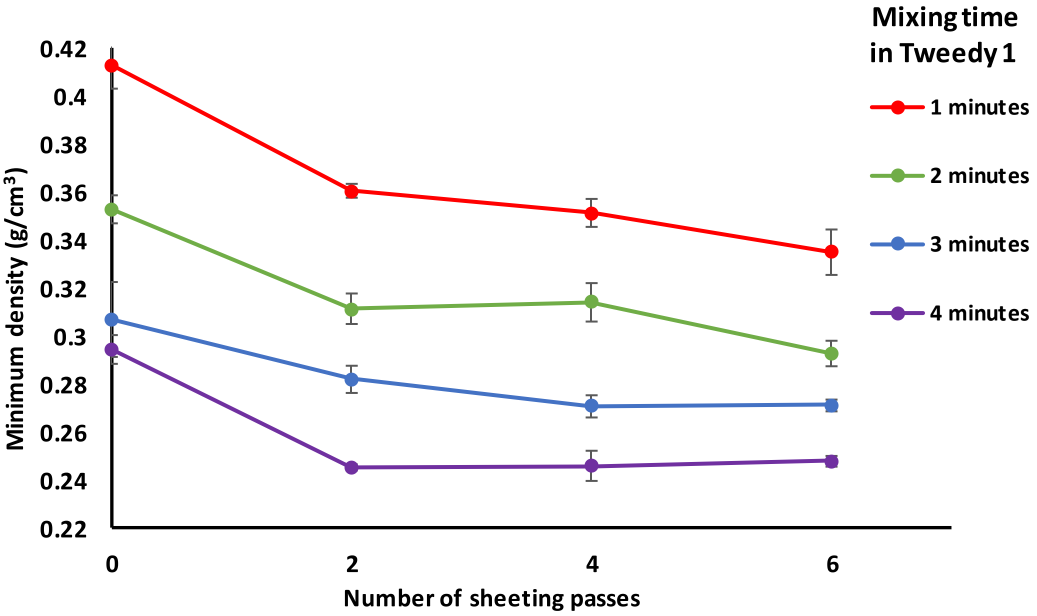


Figure 6.14 Averaged of minimum-yeasted dough density against number of sheets passes (0,2,4,6) at a roll gap setting of 6 mm and at different mixing times (1,2,3,4m) using Tweedy mixer.

6.6.2.3 *Comparison of dough development using Majorpin mixer, Tweedy mixer and Sheeter*

Figure 6.15 illustrates the minimum density of yeasted dough profiles obtained from the dynamic dough density with different numbers of sheeting passes (0, 3, 6 and 9) after 5 minutes of mixing in the MajorPin mixer, and with different mixing times in the MajorPin mixer (5, 10, 15 and 20 minutes) and in the Tweedy mixer (1, 2, 3 and 4 minutes). In order to present all the results on the same graph, the x-axis shows 1, 2, 3 and 4, representing the number of minutes mixing in the Tweedy mixer (1, 2, 3 and 4), multiplied by 5 to show the number of minutes of mixing in the MajorPin mixer (5, 10, 15 and 20), or multiplied by 3 to show the number of sheeting passes (3, 6, 9 and 12). All data are averaged from four replicate measurements, with error bars showing ±1 standard deviation of the mean, based on a pooled standard deviation.

Clearly, there is a decline in the minimum density (an increased dough expansion capacity) in both mixers and following sheeting, showing that mixing and sheeting are both effective at developing the dough. At the shorter mixing times, the Minorpin mixer appears to give better development than the Tweedy at nominally equivalent work inputs. This undoubtedly reflects the very short time for hydration in the faster Tweedy mixer, such that after 1 minute the flour has barely had a chance to become hydrated, and similarly after 2 minutes. However, by 3 and 4 minutes the doughs have become adequately developed in the Tweedy mixer and are almost identical with those mixed in the MajorPin mixer.

Meanwhile, three passes through the sheeter are sufficient to develop the dough substantially, to levels equivalent to long mixing periods (3 or 4 minutes in the Tweedy 1 mixer, 15 or 20 minutes in the MajorPin). Further sheeting appears to give a small amount of further development. However, it is clear overall; the degree of development achieved by sheeting is greater than that achieved by mixing.

As shown in Figure 6.17, there is an increase in the temperature of the dough with increasing of the mixing time; the higher temperature was recorded in the dough after mixing by Tweedy 1 mixer, indicating a greater energy input. The higher temperature increases the yeast activity, giving a greater rate of production of carbon dioxide; hence, the time to reach the minimum density is shorter for the warmer doughs, as shown in Figure 6.16. Sheeting uses much less energy and does not warm the dough significantly (Figure 6.17) or alter the time to reach the minimum density (Figure 6.16). These results illustrate how mixing of dough is an energy-intense process, and how development by sheeting offers a much more energy efficient process (and hence more environmentally friendly and cheaper), as well as offering superior dough development that is likely to lead to better quality bread.

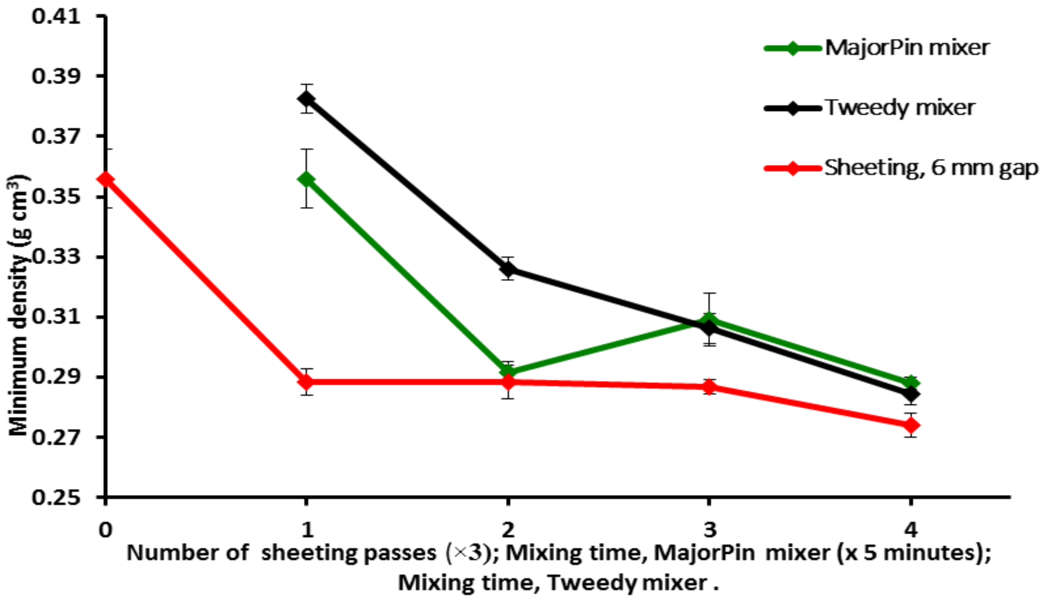


Figure 6.15 Minimum dough density against number of sheeting passes (×3 =0,3,6,9,12), mixing time in the Majorpin mixer (×5 minutes=5,10,15,20) and mixing time in the Tweedy mixer (1,2,3,4 minutes).

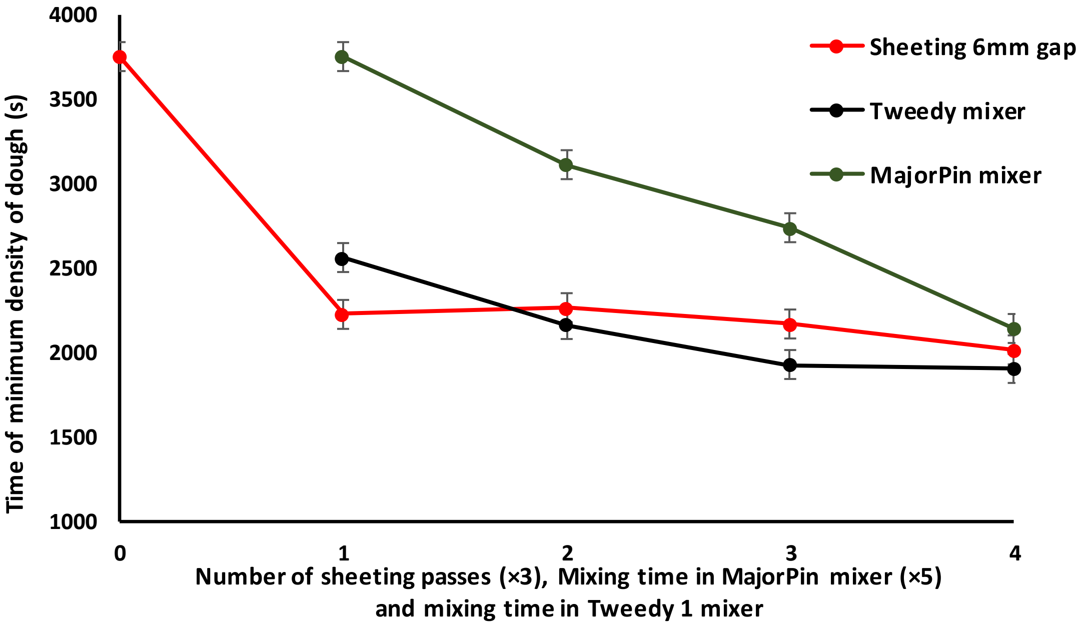


Figure 6.16 Averaged time of the minimum-yeasted dough density against number of sheeting passes (×3=0,3,6,9,12), mixing time in the MajorPin mixer (×5 minutes=5,10,15,20) and mixing time in the Tweedy mixer (1,2,3,4 minutes).

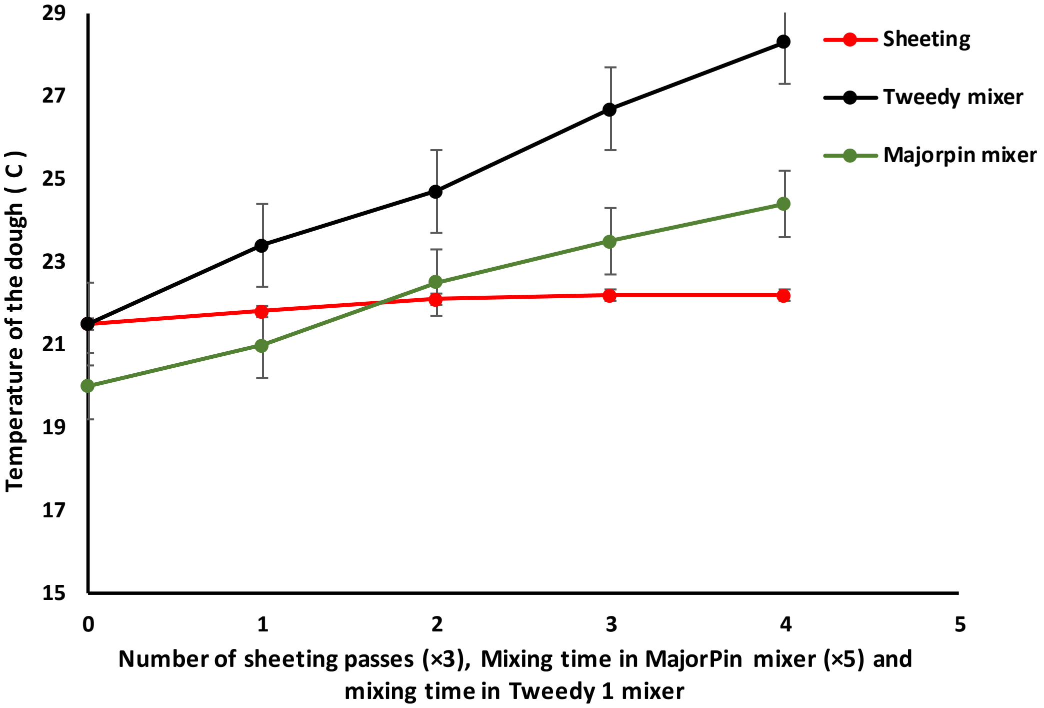


Figure 6.17 Temperature of dough against number of sheeting passes (×3=0,3,6,9,12), mixing time in the MajorPin mixer (×5 minutes=5,10,15,20) and mixing time in the Tweedy 1 mixer (1,2,3,4 minutes).

6.6.2.4 *Effects of the number of sheeting passes on baked loaf quality*

Figure 6.18 shows the specific volumes of the baked white loaves against the number of sheeting passes. Clearly, increasing the number of sheeting passes applied to the dough had an effect in increasing the final baked loaf volume up to a maximum following nine sheeting passes, after which further sheeting decreased loaf volume, suggesting overworking of the dough and damaging of the gluten structure. Kilborn and Tipples (1974) similarly found that excessive sheeting overstretched and damaged the gluten. Interestingly, the roll gap used did not appear to have a strong effect on loaf volume. The pattern is consistent with the results identified from the DDD tests as shown in figure 6.13 and 6.14 and indicates that the effects of sheeting on expansion capacity during proving were translated into effects on final baked loaf volume.

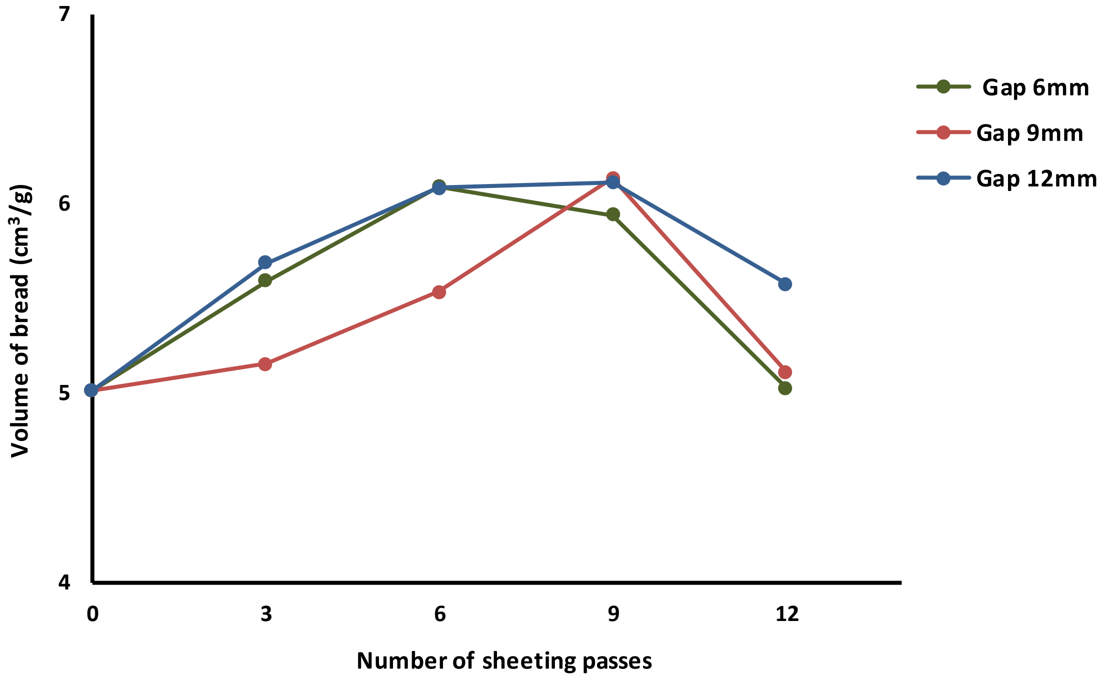


Figure 6.18 Baked white loaf volume versus number of sheeting passes at roll gap settings of 6, 9 and 12 mm, following mixing for 3 minutes in the Tweedy 1 mixer.

Figure 6.19 shows the hardness of the baked loaves versus the number of sheeting passes. It seems that sheeting three times increases hardness, after which further sheeting decreased hardness. In contrast to the effects on loaf volume, in this case there appeared to be an effect of roll gap, with larger roll gaps giving softer loaves. Loaves of the same volume, but softer, suggest a more open crumb structure in the bread, with larger gas cells. Thus it seems that sheeting with a smaller roll gaps of 6 mm gave more and/or finer bubbles in the dough, which translated to finer gas cells in the bread, and a firmer structure.

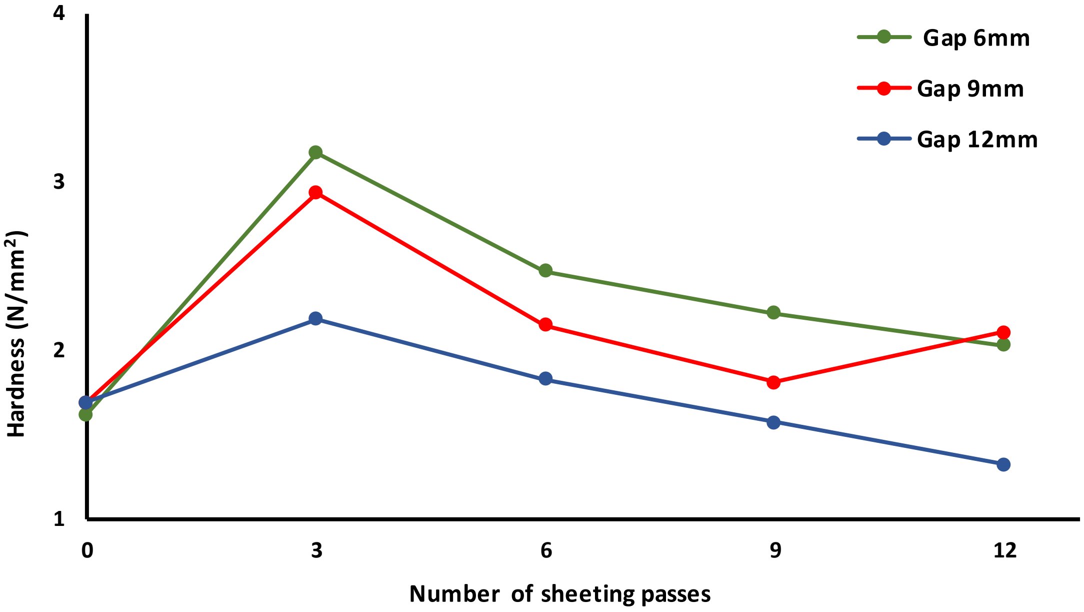


Figure 6.19 Averaged hardness of the final baked loaf (N/mm^2) against the number of sheeting passes (0, 3, 6, 9, 12) at a roll gaps of 6, 9 and 12 mm after mixing for 3 minutes using Tweedy 1 mixer.

6.6.2.5 *Effects of the number of sheeting passes at roll gap 6 mm on bran-enriched doughs development and aeration using Tweedy mixer*

In Section 6.6.2.3, the minimum density decreased (showing an increased dough expansion capacity) following mixing and sheeting at a roll gap of 6 mm. The results also showed the Tweedy 1 mixer has higher effectiveness in developing dough compared to the MajorPin mixer. Based on these results, the Tweedy 1 mixer and sheeting at roll gap 6 mm were chosen to apply to study the effect of bran on the characteristics of the dough during sheeting.

Figure 6.20 shows the density of dough mixed with bran (coarse or fine) during the DDD test, and Figure 6.21 shows the minimum density achieved after sheeting at 6 mm for 3, 6, 9 and 12 passes for doughs containing milled (Fine) and unmilled (Coarse) bran. From Figure 6.20, it seems that the densities initially of dough containing Fine bran were higher than that those containing unmilled Coarse, indicating less aeration with Fine bran, in agreement with Campbell et al. (2008a). As shown in Figure 6.21, as for white flour doughs, sheeting decreased the minimum dough density. Milling the bran gave higher minimum densities, indicating that small particles of bran damage the ability of doughs to expand more than large particles of bran, in agreement with the findings of Campbell et al.(2008a), Collins et al. (1985), Collins & Young, (1986), De Kock et al. (1999) and Zhang & Moore (1997, 1999).

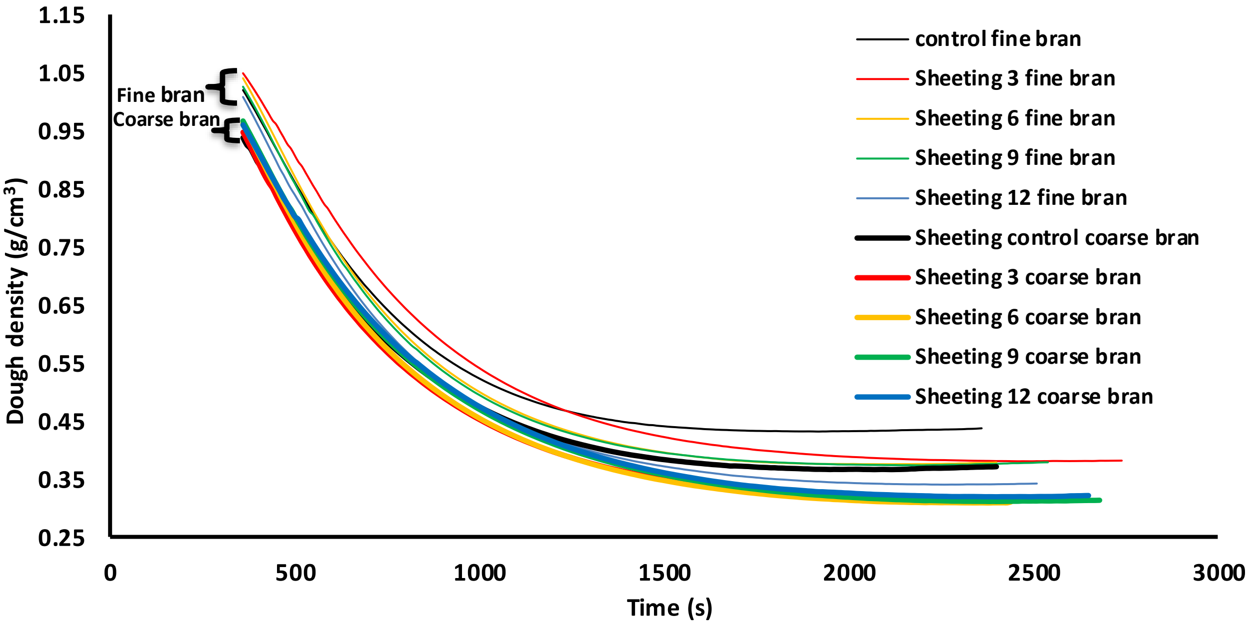


Figure 6.20 Average Dynamic yeasted dough density containing milled and unmilled bran (Fine bran and coarse bran) profiles for sheeted dough.

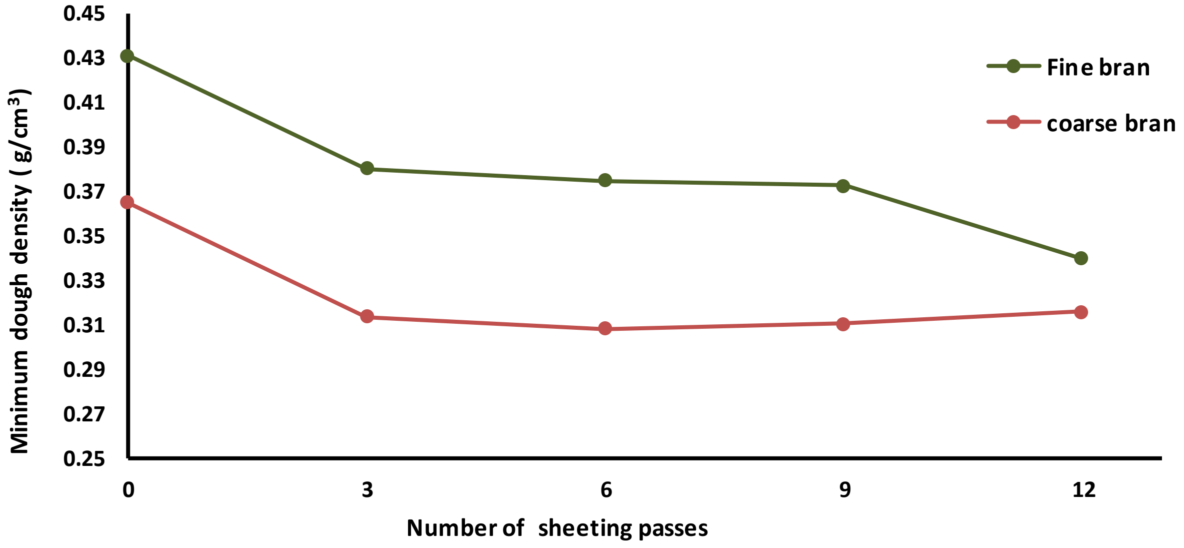


Figure 6.21 Minimum DDD density for doughs containing Fine and Coarse bran, mixed for 3 minutes in the Tweedy mixer, then sheeted at a roll gap setting of 6 mm.

Figure 6.22 shows the time taken to reach the minimum density of doughs with Fine bran and Coarse bran. The time to minimum density for doughs containing Coarse bran is higher than for doughs containing Fine bran, however, the time does not change with the number of sheeting passes for both doughs. This indicates the harmful effect of the Fine bran on the gluten network, resulting in not retaining the gas for a longer period during proving stage compared to the Coarse bran which gives lower density (greater expansion) because the dough is retaining gas for longer.

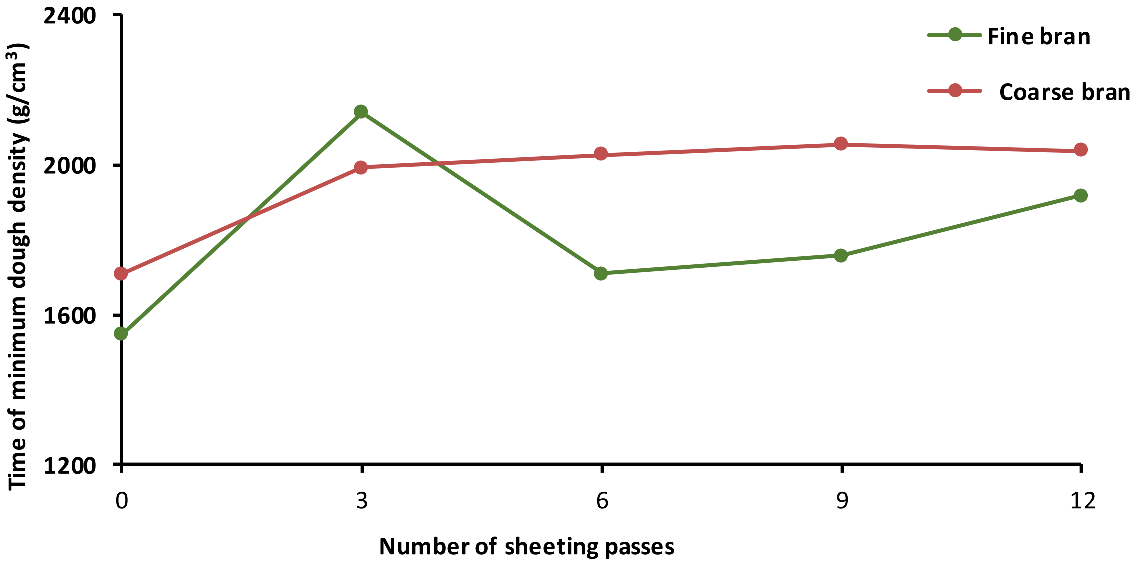


Figure 6.22 Time to minimum density, for doughs containing Fine and Coarse bran, mixed for 3 minutes in the Tweedy mixer, then sheeted at a roll gap setting of 6 mm.

6.7 Summary

For doughs both with or without bran, dynamic dough density tests showed that as the number of sheeting passes increases and the roll gap decreases, the minimum density decreases, indicating an increase in the maximum expansion capacity of the dough. Sheeting of doughs without bran for up to 12 sheeting passes decreased the minimum density of dough. Thus, the minimum dough density following just mixing was around 0.395 g/cm^3, decreasing down to around 0.35 g/cm^3 after 12 sheeting passes when using a 12 mm roll gap. For this set of trials using a 6 mm roll gap, the minimum dough density after mixing was around 0.32 g/cm^3, decreasing down to around 0.28 g/cm^3 after 12 sheeting passes. This gives a clear indication of the effectiveness of sheeting on dough development, and a basis for quantifying development and optimising sheeting processes and maximising their benefits for bread quality and energy efficiency.

The benefits of sheeting for bread quality were evident as increases in the volume and hardness of final bread produced using sheeting, i.e. the effects of sheeting on expansion capacity during proving were translated into effects on final baked loaf volume and hardness. These positive effects are due to the effects of sheeting on expansion capacity during proving and on the size and number of bubbles in the dough.

Chapter 7. Effects of bran on dough expansion and baked loaf volume and structure during sheeting

7.1 Introduction

Following the preliminary work of the previous chapter, which established the effectiveness of the Dynamic Dough Density system for quantifying effects of sheeting and of bran on dough expansion capacity, this chapter presents a more in-depth study into the effects of wheat bran and sheeting of doughs, and the interactions between these, on dough development and on baked loaf volume and structure. The effects of the level and particle size of bran on dough development by sheeting were investigated by measuring the springback of dough following sheeting and the expansion of dough using the Dynamic Dough Density system. The extent of dough development, as affected by bran and sheeting, and quantified using these measures, was then related to baked loaf quality in terms of volume and structure. Loaf volume was measured using the EinScan 3D-Sp system, and crumb structure quantified by image analysis using the C-cell bread analysis system.

7.2 Materials and methods

This section describes the details of materials, equipment and methods used to investigate the effects of sheeting on dough expansion and quality of final baked loaves for doughs formulated with different levels and particle sizes of wheat bran.

7.2.1 Bran milling and particle size determination

Commercial Coarse wheat bran was obtained from Allinson, Peterborough, PE2 9AY, UK. As explained in the Chapter 5, to obtain Medium and Fine bran samples of the same composition, this Coarse bran was milled and the size distributions of the three particles size of bran (Coarse, Medium and Fine) is measured by sieve analysis at different stainless-steel mesh sieves.

7.2.2 Dough preparation

Dough samples were prepared as described in Chapter 5; ingredients (white flour (Allinson flour, 100%), 1.5% sugar, 4% yeast, 1.6% salt, 5% fat, and water for control doughs) were mixed using Tweedy 1 mixer for 3 minutes.

In bran-enriched doughs, wheat bran (Coarse, Medium or Fine) was substituted for white wheat flour at different percentages (5, 10 and 15%), in line with previous studies of bran effects in bread (Campbell, et al., 2008a, 2008b; Gan et al., 1992; Haridas Rao & Malini Rao, 1991; Lai, Davis, et al., 1989; Moder JR et al., 1984; Pomeranz et al., 1977; Shetlar & Lyman, 1944; Zhang & Moore, 1997).

7.2.3 Effects of bran particle size, level, roll gap and number of roll passes on dough expansion and springback

Doughs with different levels and particle sizes of bran were mixed in the Tweedy 1 mixer for 3 minutes. Doughs were then sheeted at roll gaps of 6, 9 and 12 mm for 4, 8 and 12 passes. Thus the total number of trials was (three bran sizes plus a Control) × (three levels) × (three roll gaps) × (three numbers of passes) = 108 trials.

The number of trials that can be completed in one day is limited by the relative slowness of the Dynamic Dough Density test. This experiment was therefore conducted over nine days, with 12 trials per day as shown in Table 7.1, blocked for bran level and roll gap. The reasoning is that it is well established that bran level and sheeting roll gap have large effects on dough development and bread quality, whereas the effects of bran particle size and number of sheeting passes are more subtle and less well known. The day-to-day variability of dough behaviour means that, strictly speaking, experiments from different days can’t be directly compared; however, the size of the differences from bran level and roll gap were expected to be sufficiently large relative to inter-day variability to allow broad comparisons to be made, while focussing on the more novel effects of bran particle size and number of sheeting passes.

The nine days covered three different percentages of bran (5, 10 and 15%) and three roll gaps (6, 9 and 12 mm). Within each day, three particles size of bran (Coarse, Medium and Fine) were used in addition to the Control, and sheeted for 4, 8 or 12 passes. The 12 trials within each day were undertaken in a random order.

Table 7.1 Plan of experiments

Day	Size of bran	% bran	Roll gap	Number of sheeting passes	Number of samples
1	Control + 3 particles sizes	5%	6	4, 8, 12	12
2	Control + 3 particles sizes	5%	9	4, 8, 12	12
3	Control + 3 particles sizes	5%	12	4, 8, 12	12
4	Control + 3 particles sizes	10%	6	4, 8, 12	12
5	Control + 3 particles sizes	10%	9	4, 8, 12	12
6	Control + 3 particles sizes	10%	12	4, 8, 12	12
7	Control + 3 particles sizes	15%	6	4, 8, 12	12
8	Control + 3 particles sizes	15%	9	4, 8, 12	12
9	Control + 3 particles sizes	15%	12	4, 8, 12	12
				Total	108

Immediately after mixing, the doughs were sheeted through the manual sheeter at roll gaps of 6, 9 or 12 mm for 4, 8 or 12 passes. After each sheeting pass, the elongated dough piece was folded and turned before the next sheeting pass. After the final sheeting when using the 6 and 9 mm gaps, the elongated dough piece was folded and passed through a 12 mm gap to get a consistent final thickness. The 4, 8 and 12 total sheeting passes were undertaken in a random order, along with a zero-pass sample that was the dough immediately from the mixer.

Springback was measured by measuring the thickness of the dough after sheeting using the Digital Depth Gauge (described in Section 5.3.8), with springback calculated as dough thickness/roll gap. The thickness was measured at four different points of the sheeted dough piece, each time to an accuracy of 0.01 mm. Four replicate samples were taken from each dough after sheeting and their expansion measured in the DDD system.

7.2.4 Baking Bread

The effects of bran and sheeting on bread quality (loaf volume and crumb structure) were investigated. Due to the greater complexity of baking trials and limited availability of the C-Cell (kindly lent to us by Calibre Control International), the baking trials did not investigate the full range of conditions of the above sheeting trials. Baking trials were performed using the same dough formulations, but just at a 10% level of Coarse, Medium and Fine bran addition, along with a Control sample without bran, and sheeted at just the two extreme roll gaps, 6 and 12 mm, each for 4, 8 and 12 passes. Thus, a total of 24 baking trials were performed (2 gaps × 3 passes × (3 bran particle sizes plus a Control)).

Doughs were mixed in the Tweedy 1 mixer and sheeted, then from each sheet four pieces were taken using the rectangular cutter as shown in Figure 7.1, which shows the pieces of dough before and after proving and the final baked loaves. The samples were transferred to proving at 43°C for 40 minutes, then baked at 175°C for 27 minutes in a Hotpoint oven. Four loaves were baked for each formulation and sheeting pass (4, 8 and 12 passes) at 6 and 12 mm roll gaps, to give a total of (3 bran particle sizes plus a Control) × 3 sheeting passes × 2 roll gaps × 4 loaves = 96 loaves baked. The volume of each loaf was measured using the 96 loaves as overall of samples with three slices from each of the four loaves to give the overall 288 slices were analysed by C-Cell. The volume of final loaves and the crumb cell structure were measured by the 3D scanner and by C-Cell imaging, respectively, as described below.

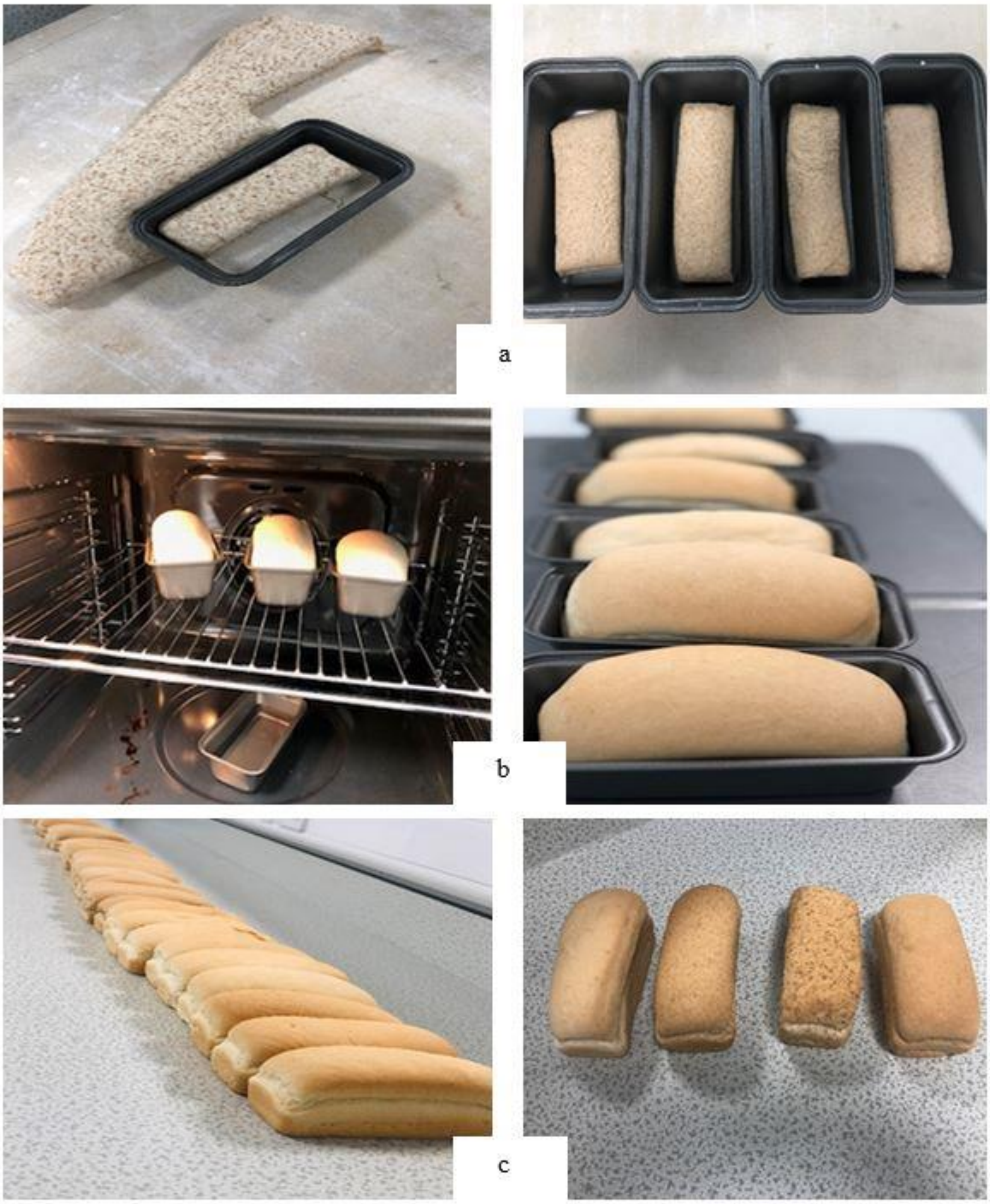


Figure 7.1 Approximately 100 g sheeted dough pieces (a), after proving (b) and after baking (c).

7.2.5 EinScan-SP 3-D scanner

In earlier chapters, the rapeseed method was used to estimate the volume of final baked loaves (AACC method 10- 05.01, AACC). In contrast, in this chapter of the study, a new method was used to measure the volume of final baked loaves, based on three-dimensional imaging using an EINSCAN-SP 3D Scanner. After taking images by 3D Scanner, the Meshmixer program was used to calculate the final baked bread, as described in Section 5.3.5.2.

7.2.6 C-cell imaging analysis of crumb structure

C-Cell colour system was used to quantify the crumb structure of the baked loaves. After cutting the bread into slices of 12 mm thickness using a bread slicer, the central three slices were used to conduct crumb structure analysis. The C-Cell uses image analysis to quantify numerous elements of crumb structure including things like the elongation of cells in different parts of the loaf. For the current, study, it was expected that sheeting and the presence of bran particles would affect gluten development, and that this would show up primarily as effects on the number of cells, mean cell diameter and the mean cell wall thickness.

7.2.7 Statistical analysis

Four DDD tests and four springback measurements were performed for each sample. For baking trials, four loaves were baked and their volumes measured, with three slices from each of the four loaves analysed by C-Cell. For each measurement, a pooled standard deviation was calculated using Microsoft Excel. Error bars are presented as ±1 standard deviation of the mean. The Pearson correlations is applied for relationship between springback and volume of bread.

7.3 Results and Discussion

7.3.1 Wheat bran particle size

Figure 7.2 shows the Coarse unmilled bran and the Medium and Fine brans produced by milling. Table 7.2 reports the sieve analysis data for each bran, and Figure 7.3 presents the cumulative particle size distributions, from which the mean particle size, x_{50}, was determined as 1262 µm for the Coarse bran, 385 µm for the Medium bran and 174 µm for the Fine bran.

Figure 7.2 Coarse bran (right), Medium bran (middle) and Fine bran (left).

Table 7.2 Coarse, Medium and Fine wheat bran particle size distribution

Sieve aperture size (µm)	Average of the bran retained weight (g)	% total weight on each sieve	Size (µm)	% Passing
Coarse				
2000	69.67	21	4000	100
1700	23.43	7	2000	79
1400	38.76	12	1700	72
710	168.61	51	1400	60
355	24.18	7	710	10
180	4.16	1	355	3
90	4.43	1	180	1
53	0.00	0	90	0
Medium				
2000	0.00	0.00	0.00	100
1700	0.00	0.00	0.00	100
1400	0.00	0.00	0.00	100
710	53.72	27.53	1400	100
355	47.98	24.59	710	72
180	38.69	19.82	355	48
90	33.57	17.20	180	28
53	21.15	10.84	90	11
Fine				
2000	0.00	0.00	0.00	100
1700	0.00	0.00	0.00	100
1400	0.00	0.00	0.00	100
710	9.53	4.78	1400	100
355	32.68	16.41	710	95
180	51.03	25.63	355	79
90	83.99	42.18	180	53
53	21.87	10.98	90	11

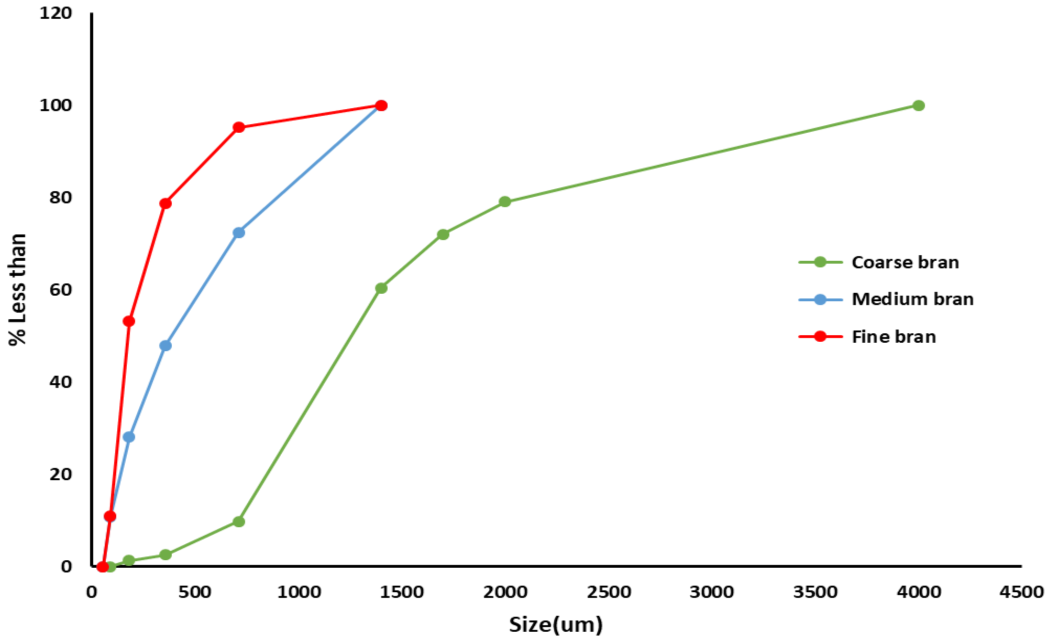


Figure 7.3 Cumulative particle size distributions of Coarse, Medium and Fine wheat bran samples.

7.3.2 Effects of bran particle size, level, roll gap and number of roll passes on dough expansion and springback

This section discusses the effects of sheeting on DDD expansion and springback for dough formulations containing different particles sizes and levels of bran.

Figure 7.5 and 7.6 show the DDD expansion and springback of doughs mixed with bran (Coarse, Medium and Fine) at three levels of addition (5, 10 and 15%, along with a Control with no bran), and sheeted at different roll gaps (6, 9 and 12 mm) for different numbers of sheeting passes (4, 8 and 12 passes). Note that the error bars are ±1 standard deviation of the mean, with a pooled standard deviation calculated from the entire data set for each bran level.

Figure 7.4 shows the results at a 5% level of bran addition. Considering the Control dough with no bran, clearly sheeting increased both the expansion and springback of the dough, in line with results in Chapter 6. Addition of bran decreased expansion and springback, also in line with earlier results and with previous literature reports (Campbell et al., 2008a-c). Fine bran was consistently the most damaging to expansion and springback, while Medium bran was consistently the least damaging, with Coarse in between. This implies that it is possible to minimise the damage to dough development caused by the presence of bran particles by optimising the size of the bran particles. It seems that Coarse bran particles are damaging because of their large size, while Fine bran particles are damaging because of their large number, but that it is possible to identify an intermediate particle size that minimises the damage.

This effect of bran particle size was generally consistent across all three roll gaps and all three numbers of sheeting passes. However, in contrast to the Control dough, the effect of sheeting the doughs with bran was initially to increase expansion from 4 to 8 passes, but then to decrease expansion on prolonged sheeting to 12 passes. So, sheeting is effective at developing gluten, as established in earlier chapters and by previous workers (Brijwani et al., 2008; Erlebach, 1998; Kilborn & Tipples, 1974; Leong & Campbell, 2008; Morgenstern et al., 1999; Moss, 1980; Patel & Chakrabarti-Bell, 2013; Stenvert et al., 1979), but the presence of bran disrupts the ever more stretched gluten sheets if the sheeting is prolonged. The efficiency of sheeting can go some way to enhancing gluten development, but in the presence of bran particles there is a limit beyond which further sheeting starts to be counter-productive.

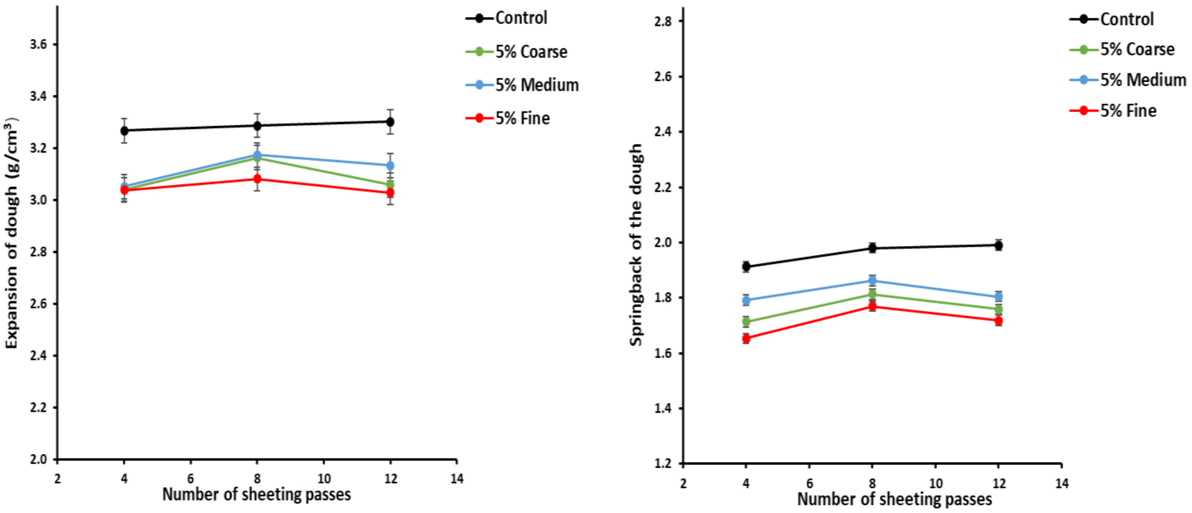
Comparing the top (6 mm roll gap), middle (9 mm) and bottom (12 mm) graphs in Figure 7.4, there is not much difference in DDD expansion between the three roll gaps. Interestingly, at 12 mm and 4 sheeting passes, the DDD expansion of all four doughs (Control and with the three different particle sizes) was similar, only diverging after 8 and 12 passes. Sheeting at 12 mm is less severe than at 6 mm, such that evidently there is not much difference in development after just 4 passes, while greater differences emerge after more sheeting. At the 5% level of bran addition, the doughs are not greatly different from the Control dough, hence similar expansions after 4 sheeting passes at 12 mm, but further sheeting starts to allow the interactions between the bran particles and the developing gluten network, and the influence of particle size on this interaction, to become apparent.

The springback results show a similar pattern between the different particles sizes at 12 mm and 4 sheeting passes, although in this case the Control dough gave more springback than the doughs with 5% bran. In general sheeting at 12 mm gave greater springback than at 6 mm, with 9 mm appearing to give the lowest springback. This pattern is also evident in the data at 10% bran addition (Figure 7.5) and at 15% bran addition (Figure 7.6).

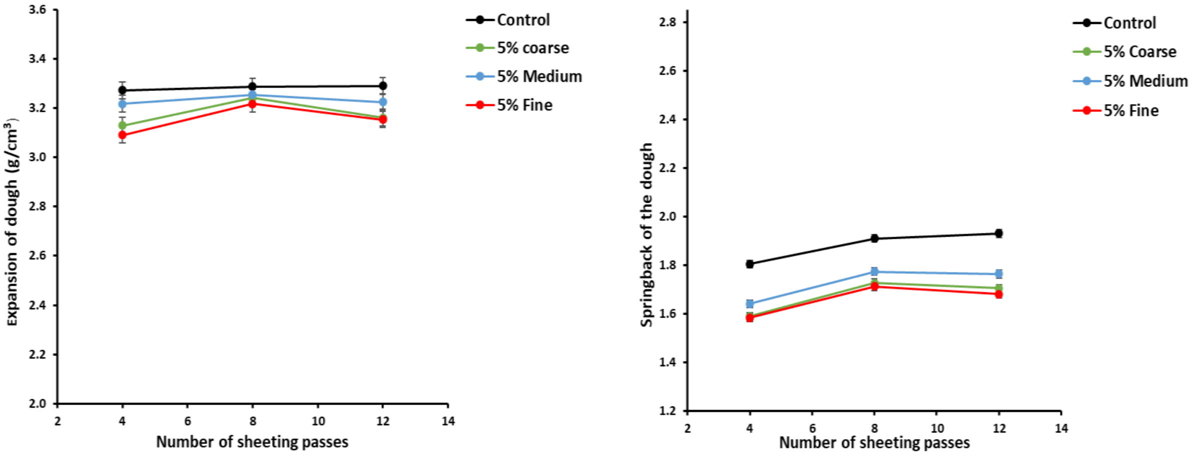
In general, the results at the higher levels of bran addition show the same trends, magnified because of the higher bran levels. In Figure 7.5 and Figure 7.6, again the Fine bran reduced expansion and springback the most, and the Medium bran the least. Again, it is evident that sheeting for 8 passes gave greater expansion and springback than after only 4 passes, for all roll gaps, but that further sheeting to 12 passes decreased expansion and springback. The consistency of these patterns across all the conditions gives confidence in the conclusion that there is an intermediate particle size and an intermediate number of sheeting passes that maximise gluten development. There is thus scope for bakers to optimise the development of doughs containing bran, by adjusting bran particle size and sheeting, in order to minimise the detrimental effects of bran on bread quality.

It is surprising that the greatest expansion and springback are seen consistently after 8 sheeting passes for all three roll gaps. Sheeting at 6 mm is more severe than at 9 or 12 mm, hence one might expect that the change from a positive to a negative effect on development might depend on the roll gap. Clearly there may be subtle differences at the intermediate passes that were not examined; possibly at 6 mm the maximum development occurs at say 6 or 7 passes, and at 9 or 10 at 12 mm. But from the current study, there is no evidence that the optimum number of sheeting passes for maximum development is strongly affected by roll gap.

Gap 6 mm (A)



Gap 9 mm (B)



Gap 12 mm (C)

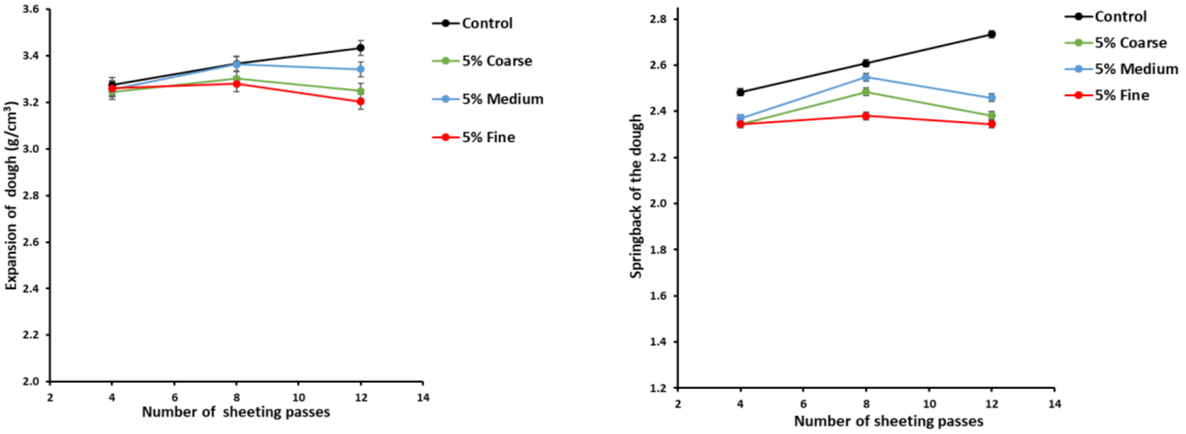
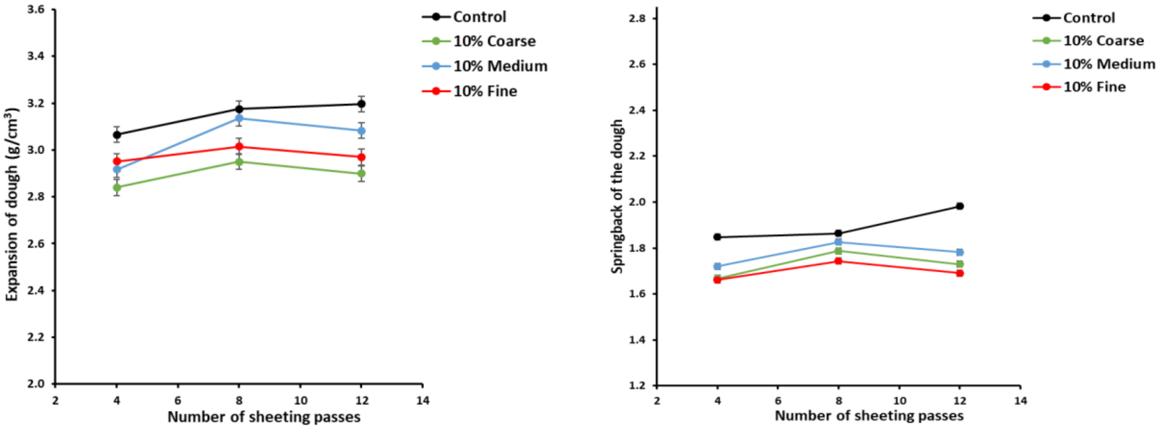
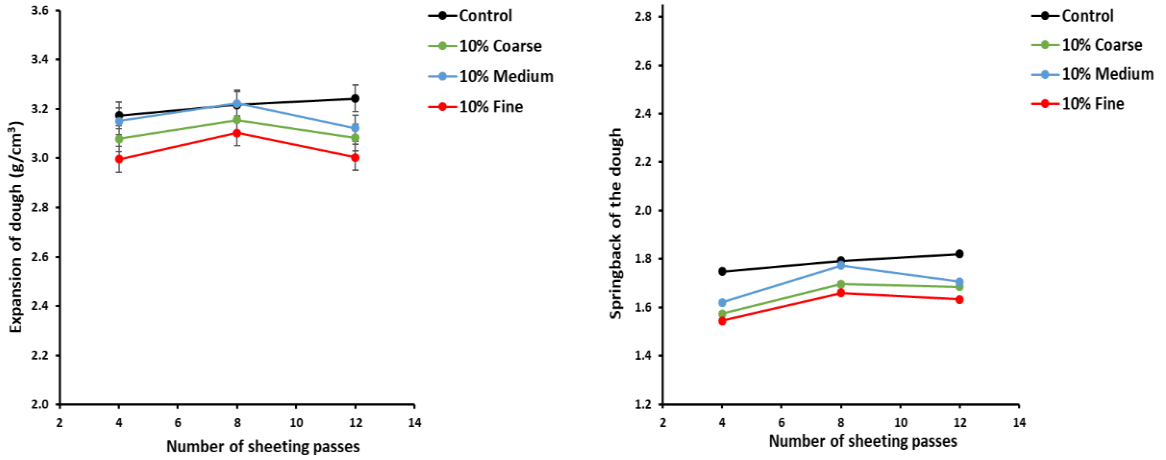


Figure 7.4 Average expansion and springback of doughs containing 5% Fine, Medium and Coarse bran, mixed for 3 minutes in the Tweedy mixer, then sheeted at roll gap settings of 6, 9 and 12 mm.

Gap 6 mm (A)



Gap 9 mm (B)



Gap 12 mm (C)

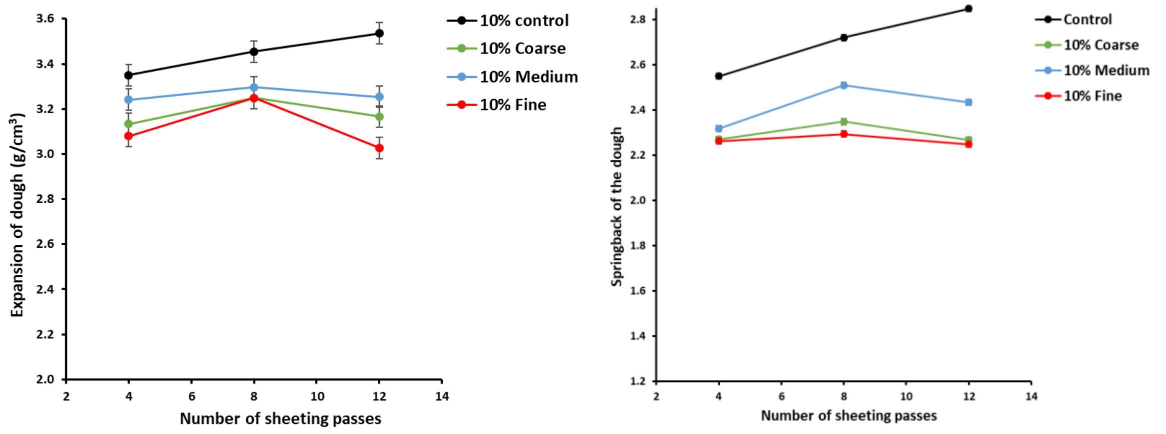
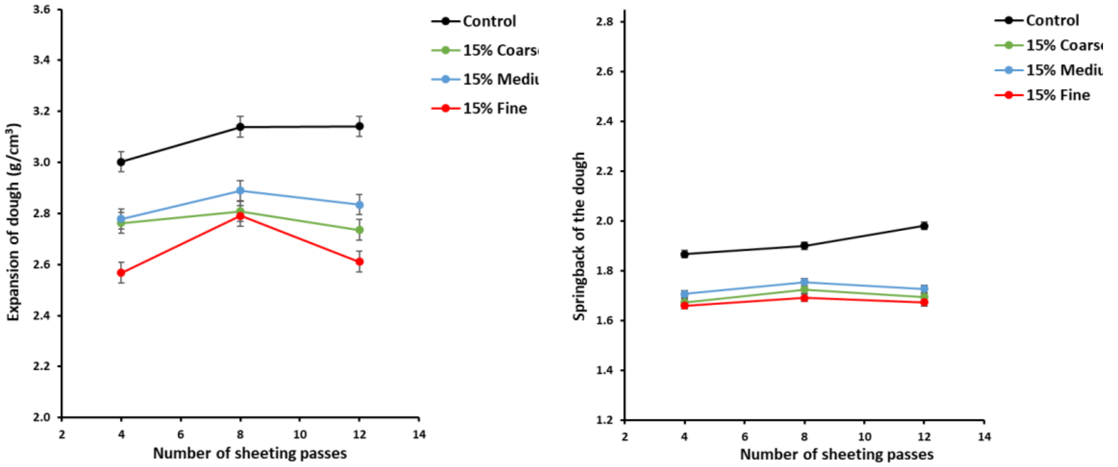
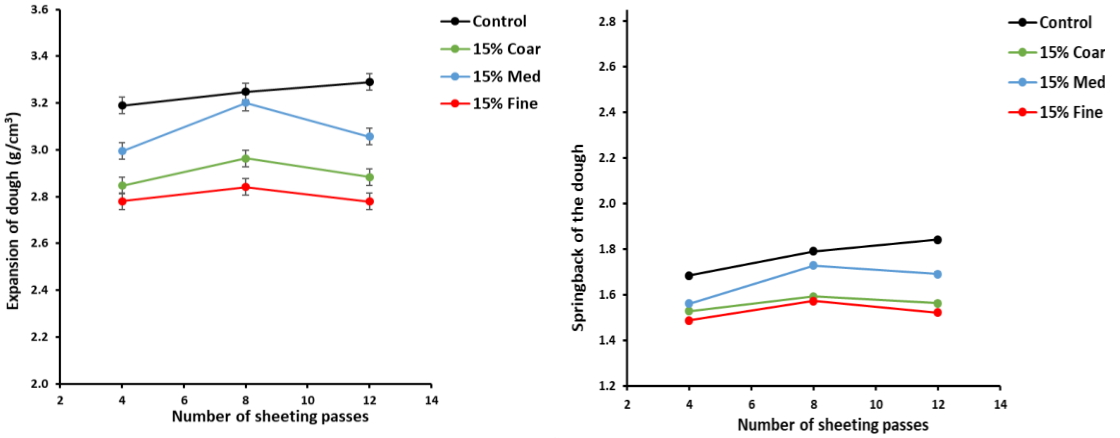


Figure 7.5 Average expansion and springback of doughs containing 10% Fine, Medium and Coarse bran, mixed for 3minutes in the Tweedy mixer, then sheeted at roll gap settings of 6, 9 and 12 mm.

Gap 6 mm (A)



Gap 9 mm (B)



Gap 12 mm (C)

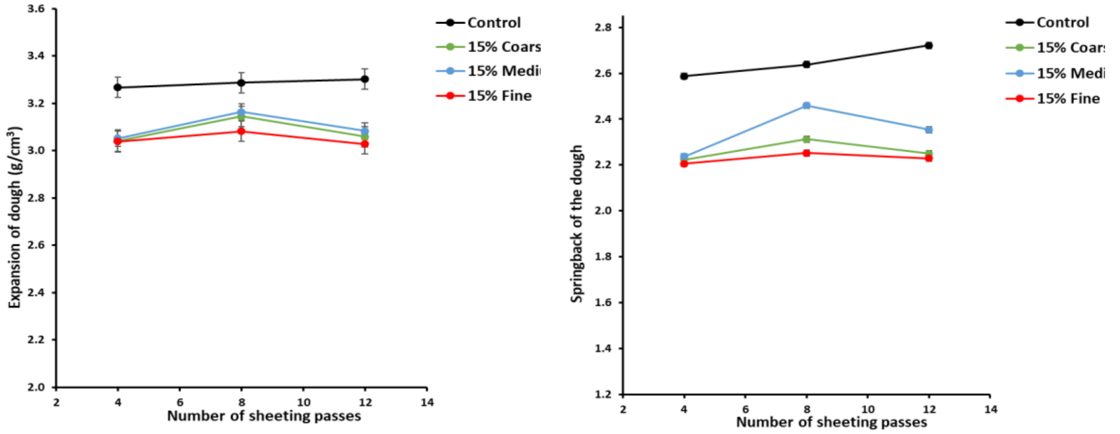


Figure 7.6 Average expansion and springback of doughs containing 15% Fine, Medium and Coarse bran, mixed for 3 minutes in the Tweedy mixer, then sheeted at roll gap settings of 6, 9 and 12 mm.

The responses of DDD expansion and springback in Figures 7.4-7.5 are very similar: both increase for the control dough as number of sheeting passes increased; both decrease on addition of bran, with Fine bran the most damaging and Medium bran the least damaging; and both show a maximum at 8 sheeting passes compared with 4 or 12. It is therefore of interest to ask if these two measures of dough development are highly correlated, and if they are in effect giving two different measures of the same phenomenon. If so, then springback is a much quicker and more convenient measure than DDD expansion, and studies with the DDD system may not be necessary.

Figures 7.7, 7.8 and 7.9 show the relationship between the DDD expansion and springback of doughs mixed with bran (Coarse, Medium and Fine) at three levels of addition (5, 10 and 15%, along with a Control with no bran), and sheeted at different roll gaps (6, 9 and 12 mm) for different numbers of sheeting passes (4, 8 and 12 passes). Clearly, in contrast to the Control dough, there is a direct relationship initially between the springback of the dough and expansion of the dough during proving in all three roll gaps from 4 to 8 passes but then the relationship changes to inverse due to the effect of sheeting on the dough expansion and springback. As shown in the figures, the relationship gives the form of the letter V in the dough with bran.

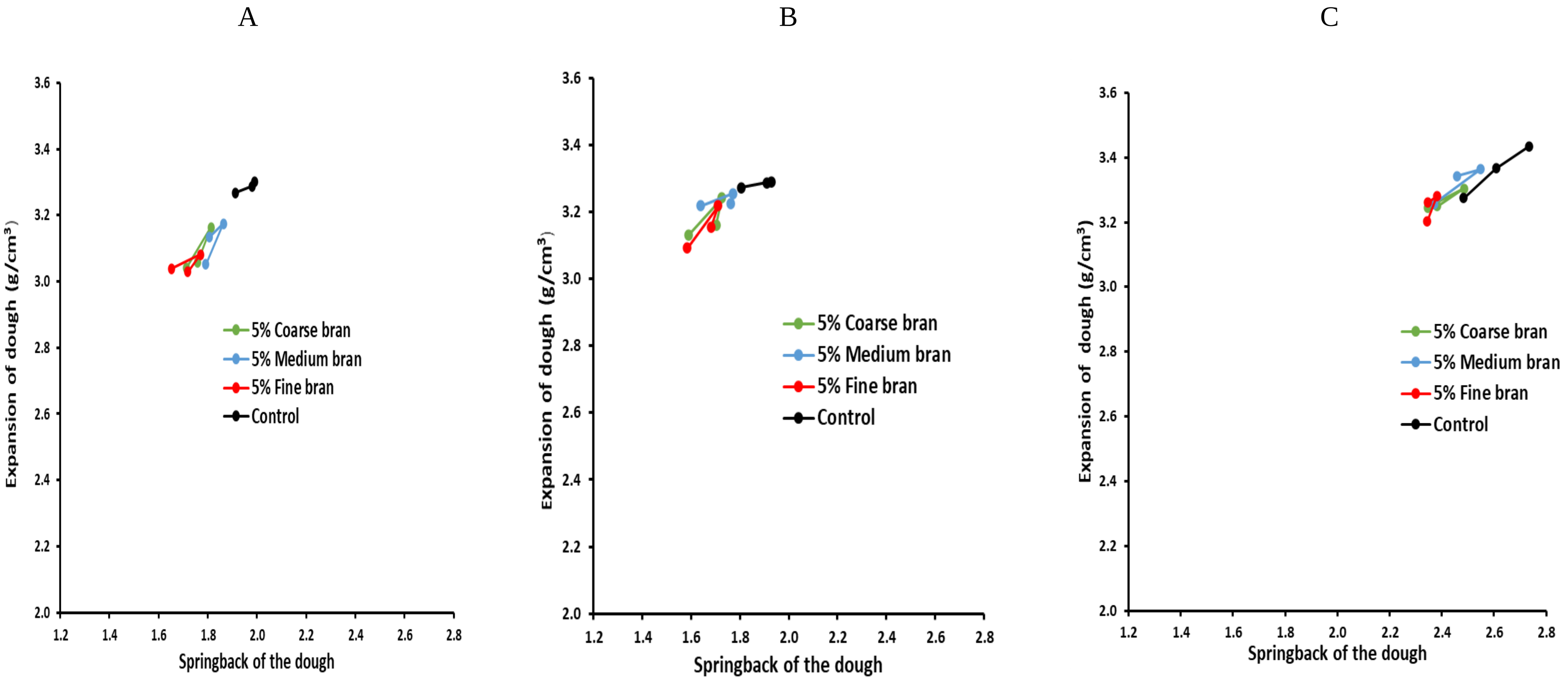


Figure 7.7 The relationship between the average of expansion and springback of doughs containing 5% Fine, Medium and Coarse bran, mixed for 3 minutes in the Tweedy mixer, then sheeted at roll gap settings of 6(a), 9(b) and 12 mm(c).

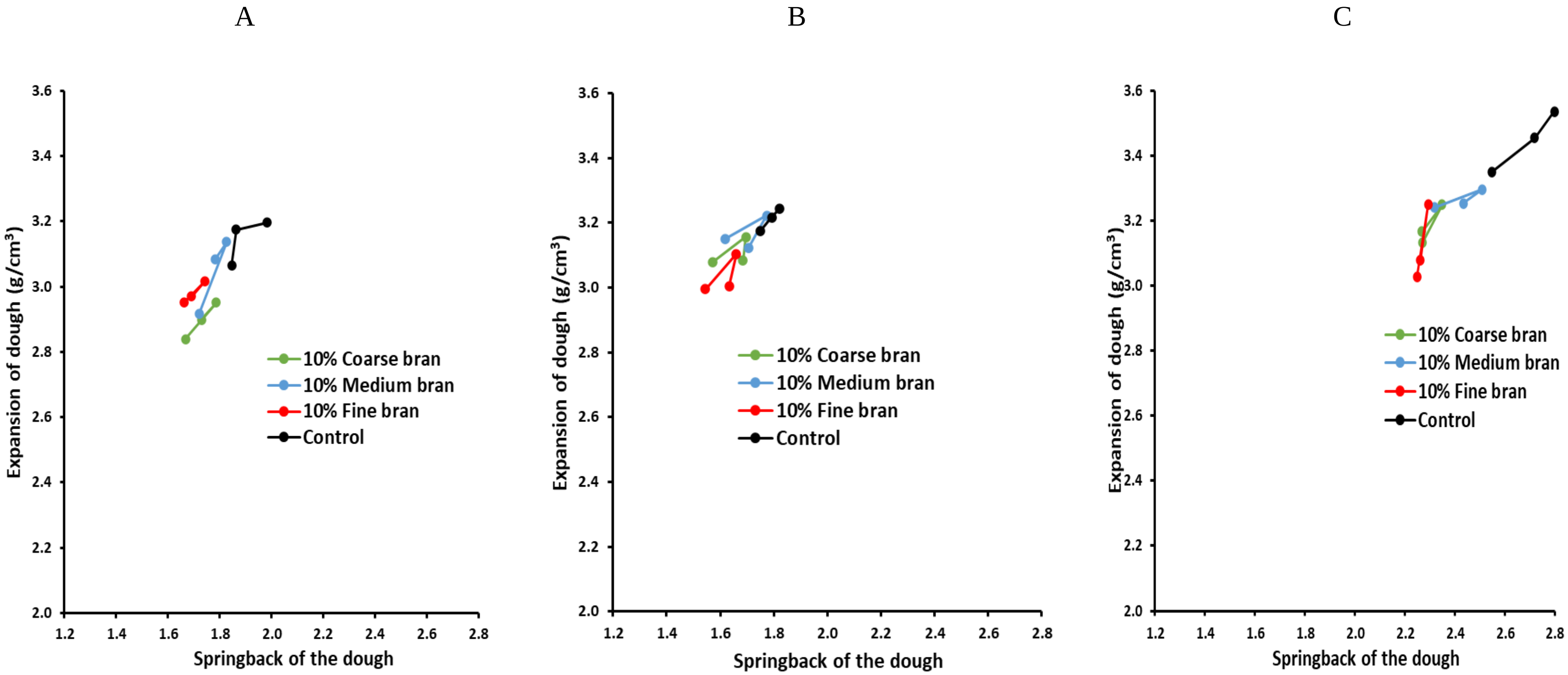


Figure 7.8 The relationship between the average of expansion and springback of doughs containing 10% Fine, Medium and Coarse bran, mixed for 3 minutes in the Tweedy mixer, then sheeted at roll gap settings of 6(a), 9(b) and 12(c) mm.

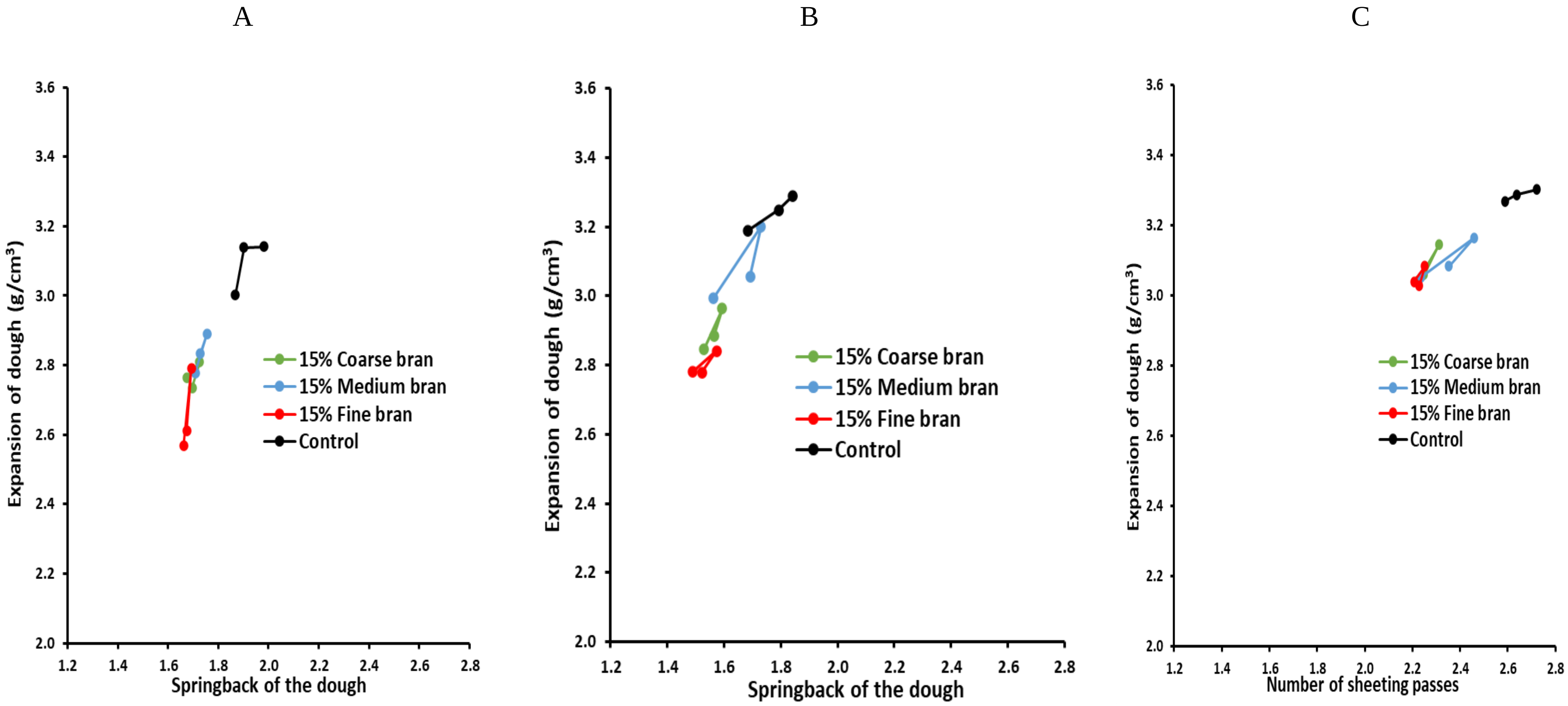


Figure 7.9 The relationship between the average of expansion and springback of doughs containing 15% Fine, Medium and Coarse bran, mixed for 3 minutes in the Tweedy mixer, then sheeted at roll gap settings of 6(a), 9(b) and 12(c) mm.

7.3.3 Investigation of effects of sheeting and bran particle size on baked loaf quality

The results from DDD expansion and springback showed that bran particle size, roll gap during sheeting and number of sheeting passes affect dough development. A further investigation was undertaken to see how this translates to effects on bread texture. Because baking trials are much more time-consuming, a smaller experimental scope was investigated. Baking trials were performed just at a 10% level of Coarse, Medium and Fine bran addition, and at just 6 and 12 mm roll gaps, each for 4, 8 and 12 passes. Thus, a total of 24 baking trials were performed (2 gaps x 3 passes x (3 bran particle sizes plus a Control)), with four loaves baked for each case, resulting in 96 loaves.

Figure 7.10 shows the springback of doughs following sheeting at 6 or 12 mm roll gaps and 4, 8 and 12 passes. As seen earlier in Figure 7.5, once again sheeting was effective at developing the control dough, while for doughs with bran, sheeting beyond 8 passes reduced springback, particularly for the 12 mm roll gap. The results are not identical to those of Figure 7.5, reflecting the inherent variability of dough studies, but they confirm the same broad trends.

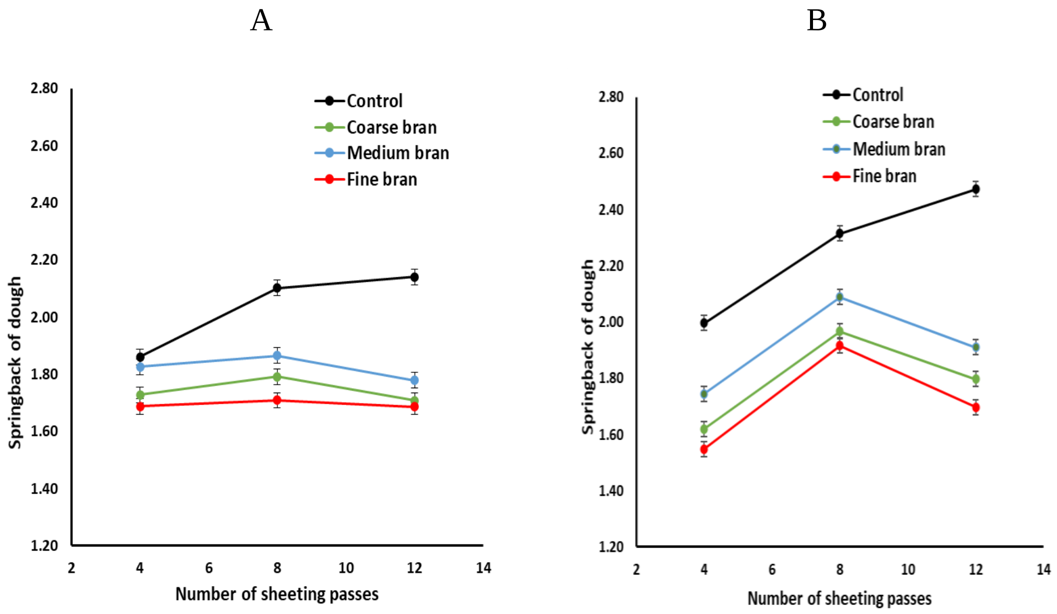


Figure 7.10 Average springback of doughs containing 10% of Fine bran, Medium bran and Coarse bran, compared with dough control, mixed for 3 minutes in the Tweedy mixer, then sheeted at a roll gap setting of 6 mm (figure a) 12 mm (figure b) for 4, 8 and 12 sheeting passes.

Doughs were weighed before baking, and loaves weighed after baking, allowing the moisture loss during baking to be calculated. Table 7.3 and Table 7.4 report the moisture loss from the doughs sheeted at 6 and 12 mm, respectively. Analysis of variance (ANOVA, shown a *p*-values in Tables 7.3 and 7.4) showed no significant effects of bran particle size or number of sheeting passes on moisture loss, which was consistently around 18 g from an initial 100 g dough piece.

Table 7.3 Average loss water (in g) from doughs containing 10% of Fine, Medium and Coarse bran, compared with the Control, for loaves baked from doughs sheeted at a roll gap setting of 6 mm for 4, 8 and 12 sheeting passes.

Number of sheeting passes	Control	Coarse bran	Medium bran	Fine bran	*p*-value
4	19.5	17.3	18.4	17.3	0.84
8	18.5	18.5	18.6	16.5	0.86
12	18.13	17.70	18.33	17.33	0.88
Pooled standard deviation	± 0.70	± 0.70	± 0.70	± 0.70	
p-value	0.057	0.058	0.055	0.053	

Table 7.4 Average loss water of doughs containing 10% of Fine, Medium and Coarse bran, compared with the Control, for loaves baked from doughs sheeted at a roll gap setting of 12 mm for 4, 8 and 12 sheeting passes.

Number of sheeting passes	Control	Coarse bran	Medium bran	Fine bran	*p*-value
4	17.4	18.5	17.6	20.6	0.67
8	18.1	18.1	18.8	16.8	0.64
12	17.5	18.6	18.1	16.7	0.62
Pooled standard deviation	±1.37	±1.37	±1.37	±1.37	
p-value	0.91	0.93	0.90	0.96	

Figure 7.11 shows the volume of baked loaves. Clearly the patterns closely mirror those from the DDD and springback results. Control doughs without bran gave the largest loaf volumes, and volume increased as sheeting increased from 4 to 8 to 12 passes at both roll gaps. Loaves were slightly larger after sheeting at a 6 mm roll gap, possibly reflecting

greater gluten development at the smaller gap. In Figure 7.12, a comparison of images of bread samples made without bran and with 10% coarse, Medium and Fine bran, and with sheeting 8 at a 6 mm roll gap. The images are descending from highest to lowest volume. Bran decreased loaf volume, with Fine bran once again the most damaging and Medium bran the least, and with sheeting for 8 passes once again optimal compared with 4 or 12 passes.

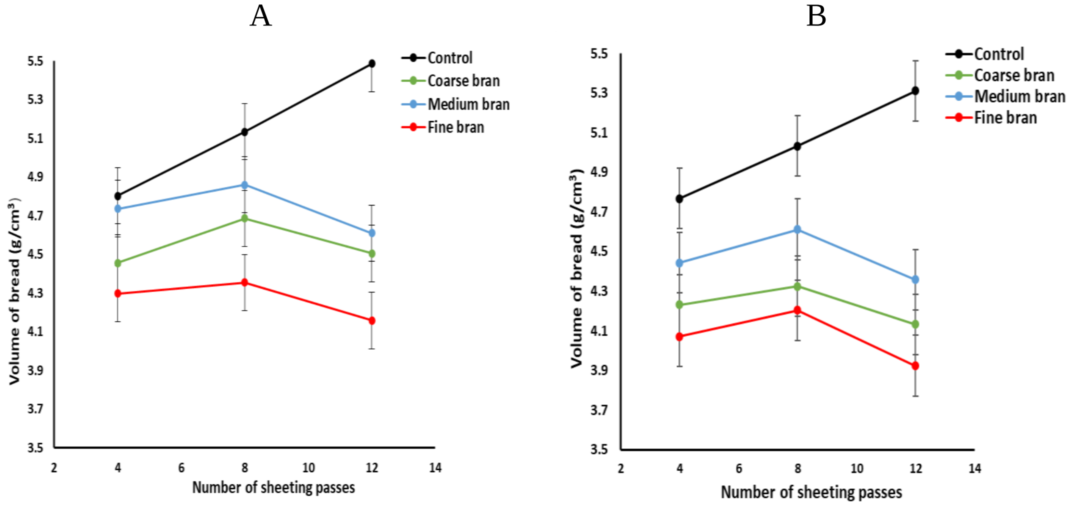


Figure 7.11 Average Volume of final baked loaf containing 10% of Fine, Medium and Coarse bran, compared with loaf control, the doughs were mixed for 3 minutes in the Tweedy mixer, then sheeted at a roll gap setting of 6 mm (figure a) 12 mm (figure b) for 4, 8 and 12 sheeting passes.

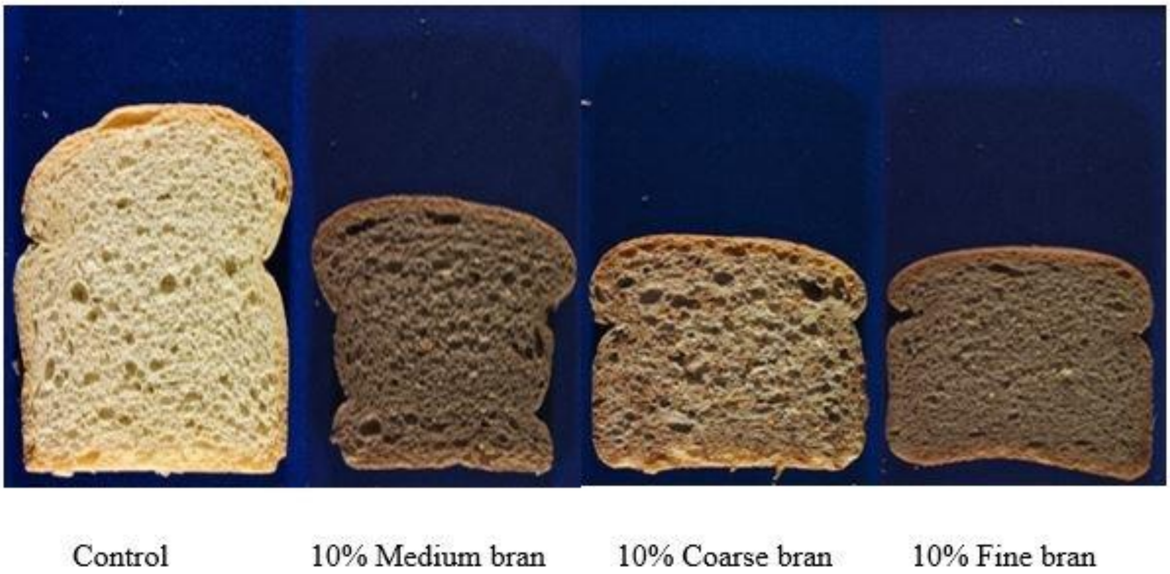


Figure 7.12 Effects of sheeting on loaf volumes and crumb structures containing 10% of Fine, Medium and Coarse bran, compared with loaf control, the doughs were mixed for 3 minutes in the Tweedy mixer, then sheeted at a roll gap 12 mm 8 sheeting passes. Showing loaf volume, the crumbs are ordered from the highest volume to the lowest volume

Figure 7.13 shows the relationship between the springback of the dough with the volume of the final baked bread. Unlike Control samples, the relationship also gives the form of the letter V in the dough with bran. The results were subjected to a study of the correlation between Springback and volume of bread using Pearson correlation analysis. The results of the statistical analysis showed a direct relationship between them, as it was strong when at roll gap 6 mm in all the particles size of bran volumes along with the control, and the correlation coefficient (R) was recorded 0.91, 0.90, 0.99 and 0.78 for Control, Coarse, Medium and Fine, respectively, and the correlation coefficient was a medium at 12 mm for Coarse, Medium and Fine in which is respectively 0.45, 0.67 and 0.45, while it was strong for control in the same roll gap 12 mm in which recorded 0.97. This is consistent with the results identified from relationship between the DDD expansion with the springback and indicates that the effects of bran on expansion capacity during proving were translated into effects on final baked loaf volume as show in Figure 7.14 which presents the comparation between the springback of the dough with the number sheeting of the dough with the C-Cell images of the slices of final baked bread. Thus there is clear evidence that dough development as indicated by springback is reflected in the volume of the baked loaf.

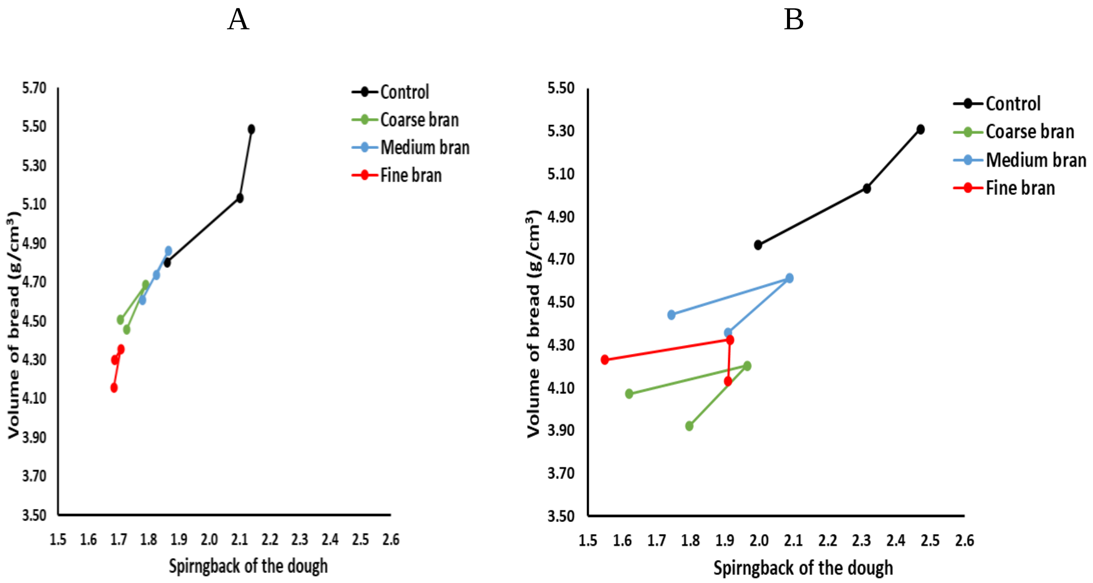


Figure 7.13 The relationship between springack of dough and volume of final baked bread containing 10% of Fine, Medium and Coarse bran, compared with loaf control, the doughs were mixed for 3 minutes in the Tweedy mixer, then sheeted at a roll gap setting of (A) 6 mm and (B) 12 mm for 4, 8 and 12 sheeting passes.

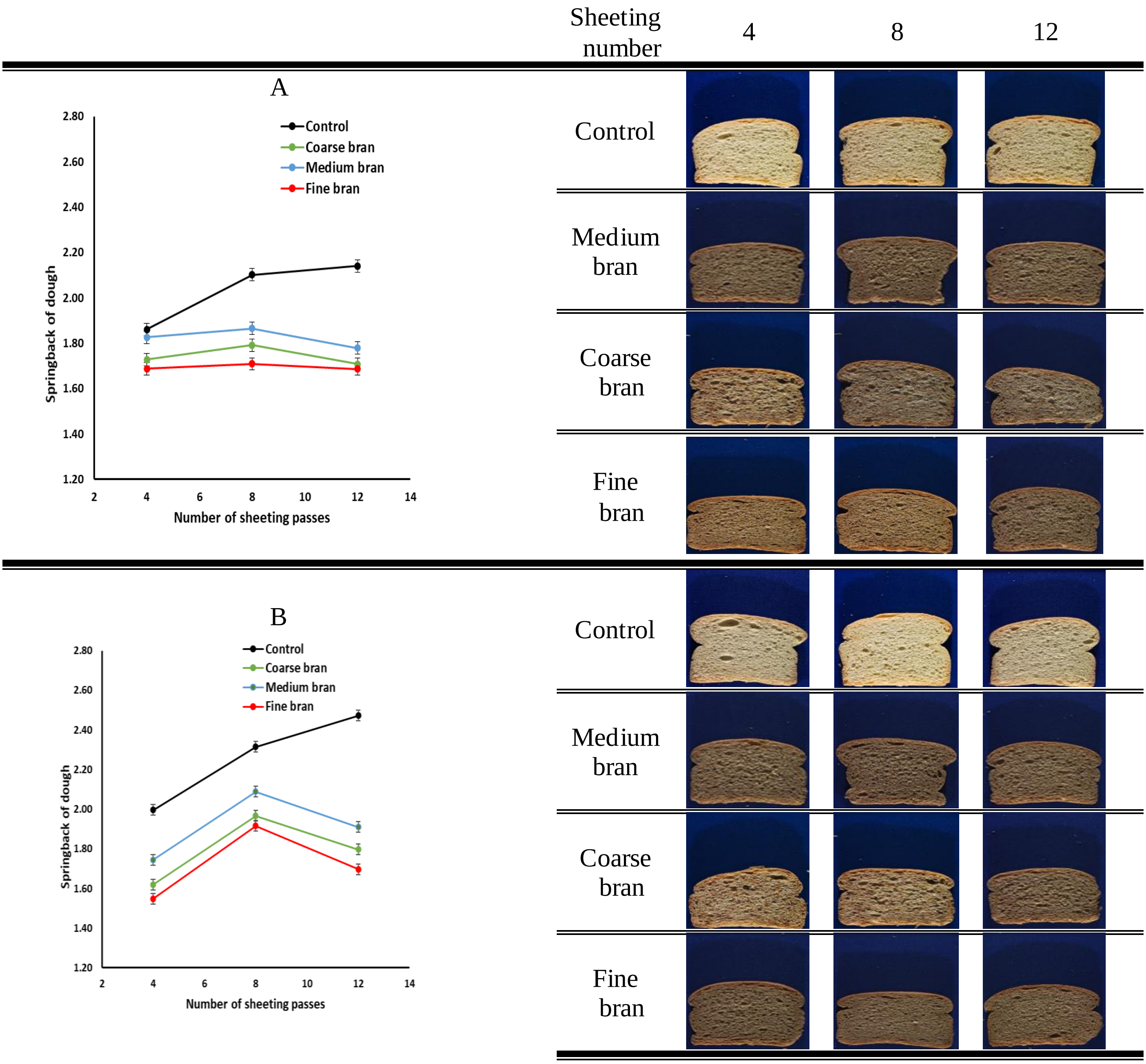


Figure 7.14 The relationship between the springback of the dough and volume of bread crumb containing 10% of Fine, Medium and Coarse bran, compared with loaf control, the doughs were mixed for 3 minutes in the Tweedy mixer, then sheeted at a roll gaps setting of 6 mm (figure a) 12 mm (figure b) for 4, 8 and 12 sheeting passes.

As well as giving a large loaf volume, good gluten development should retard coalescence of bubbles during proving and baking, leading to a large number of gas cells with small diameters and thin walls. Figures 7.15, 7.16 and 7.17 show the number of cells and the average cell diameter and wall thickness as affected by bran particle size and sheeting. As the degrees of sheeting passes for the dough increased, gas cell volume (cell diameter) increased and the number of cells decreased (Figures 7.15 and 7.16). At both roll gaps, 6 and 12 mm, control bread had a higher number of cells, but the volume and wall thickness of the cells was lower (Figure 7.17). Clearly the addition of bran affects the number of cells and the volume of cell in final baked bread. C-Cell results also show that the Fine bran gave more cells than the Medium and Coarse bran, the latter giving the lowest number of cells with larger diameters and wall thicknesses, as also evident in Figure 7.18 which shows C-Cell images of bread slices. Clearly, the Coarse bran gave a more open structure for the crumb than the Control and the Medium and Fine bran. The Control and Fine bran gave softer textures due to the higher number of bubbles, in agreement with Thompson (2008), Gonzales-Barron and Butler (2005), Wang et al. (2017), Chamberlain and Collins (1979) and Millar et al. (2019).

When focusing on the images of baked loaves that taken by C-Cell in Figure 7.18, the loaves containing Fine bran are clearly identified giving very small gas cells compared to those containing Coarse bran that gives larger cells and open structure. The results also showed that the bran has an effect on the thickness of the walls of the gas cells, where the highest values were recorded in the bread from the Coarse particles. Also, the results showed a close correlation between the thickness of the wall with those of the gas cell diameter, due to similar patterns in the directions of each of them (shown in Figures 7.16

and 7.17). Thin cell walls may be a useful feature in improving the quality of baked products and making them more desirable, and adding bran may cause harm (Qi et al., 2008; Si & Drost-Lustenberger, 2002; Sørensen, 2003). However, some studies recommend grinding or milling to produce microscopic particles in order to reduce the thickness of the cell wall in final baked wholemeal loaves (Collins & Hook, 1991; De Kock et al., 1999; Haridas Rao & Malini Rao, 1991; Hook, 1987; Lai et al., 1989a; Moder et al., 1984; Moss, 1989; Nelles et al., 1998; Özboy & Köksel, 1997; Pomeranz et al., 1977; Rasco et al., 1991; Shetlar & Lyman, 1944).

In general, sheeting the doughs from 4 to 8 passes with bran increased the number of cells, but the number then decreased at 12 passes for all formulations of bread. In contrast to the Coarse bran, the volume and wall thickness of cells of baked loves with Medium and Fine bran increased with increasing the number of sheeting from 4 to 8 passes, but then the volume and wall thickness of cell decreased on prolonged sheeting to 12 passes. This may be the result that gas produced during fermentation is typically transported to gas nuclei that were formed during dough mixing (Gan et al., 1990), and the greater gas production in dough systems with different size of bran could result in different size of large gas cells. Those large gas cells expand during baking, creating an “open” crumb structure in the resultant bread. Alternatively, gas cells can coalesce during bread making when bran is added because of the excessive swelling of gluten net.

The C-Cell results are consistent with the results of the springback and the volume of bread. Hence, there is a relationship between increasing the thickness of the dough after each degree of sheeting and the development of gluten, which in turn helps to maintain gas retention inside the dough, and this positive effect is transmitted to the final bread containing a large number of cells.

Bran increases aeration during mixing as well as during sheeting, with Medium bran increasing the gas content of doughs more than Coarse and Fine bran. Bran depresses gas retention during proving, resulting in lower baked loaf volumes, with Fine bran having a more detrimental effect than Coarse and Medium bran. Bran gives larger gas cells in baked loaves, Medium more so than Coarse and Fine. Despite the detrimental effects of adding bran of all particles sizes, sheeting is effective in reducing these effects by enhancing the development of the dough, which positively affects the volume and quality of the final baked loaf, with Fine bran particles having more of a detrimental effect than Medium and Coarse bran. This is consistent with the results identified from the springback of dough which are new results and there are no previous studies related. The results indicate that the effects of sheeting on development of the dough were translated into effects on expansion capacity during proving, then these effects were translated into effects on final baked loaf volume. The negative effect of bran on baked bread quality is due to the bran particles that damage to the structure and as a result, loss of gas. This damage is thought to be caused by disruption of the gluten films responsible for developing the dough, reducing the volume of gas that the structure retains due to effects of the bran particles (Gan et al., 1992; Pomeranz et al., 1977). Furthermore, the conclusion that the Medium and Coarse bran had less detrimental effects than Fine bran is in agreement with research by Thompson (2008).

Comparing the roll gaps, 6 and 12 mm, there is not much difference in C-Cell results between them. Interestingly, at 12 mm and three sheeting passes, the number of cells of all final baked loaves (Control and with the three different particle sizes) were more than bread from doughs sheeted at 6 mm, but the diameter and wall thickness of cells were higher. Small gas cell diameters are a positive advantage in bread loaves (Başman & Köksel, 1999; Cauvain et al., 1983) and milling of bran particles is one of the recommended steps for production of high-quality loaves (Collins & Hook, 1991; De Kock et al., 1999; Haridas Rao & Malini Rao, 1991; Hook, 1987; Lai et al., 1989a; Moder JR et al., 1984; Moss, 1989; Nelles et al., 1998; Özboy & Köksel, 1997; Pomeranz et al., 1977; Rasco et al., 1991; Shetlar & Lyman, 1944). The presence of bran, especially fine bran, reduces the overall volume of loaves, and this decrease in the overall volume arises from smaller individual gas cells with a loaf, which produces a smaller and denser loaf. Therefore, although the presence of small cells in loaves is classified as a beneficial feature, the decrease in overall volume is not certainly so (Campbell et al., 2008; Campbell et al., 2008a; Collins et al., 1985; Collins & Young, 1986; De Kock et al., 1999; Zhang & Moore, 1997; Zhang & Moore, 1999). The quality of bread may be negatively affected by the presence of smaller gas cells, mainly when the density and hardness of the final bread are greater than for loaves containing Coarse bran.

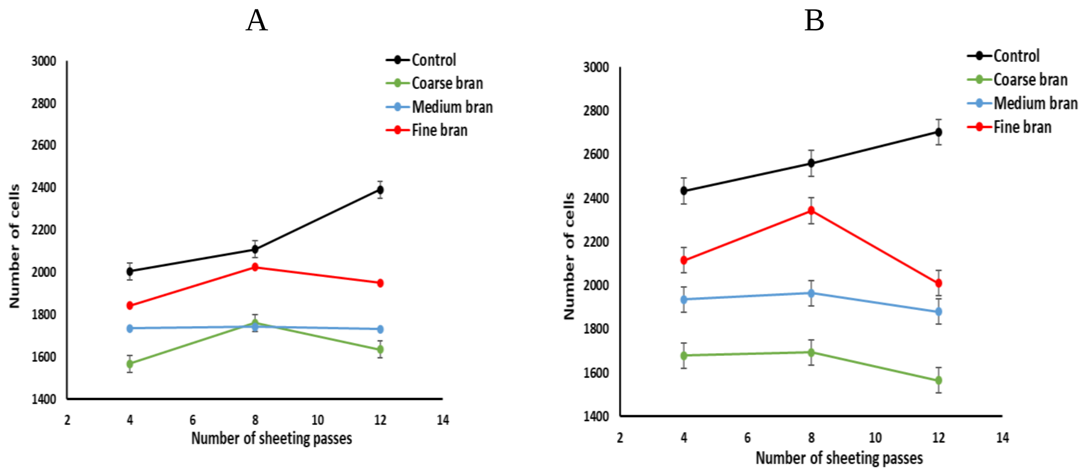


Figure 7.15 Average number of cells for final baked loaves containing 10% of Fine, Medium and Coarse bran, compared with the Control. Doughs were mixed for 3 minutes in the Tweedy mixer, then sheeted for 4, 8 and 12 sheeting passes at a roll gap setting of (A) 6 mm; and (B) 12 mm.

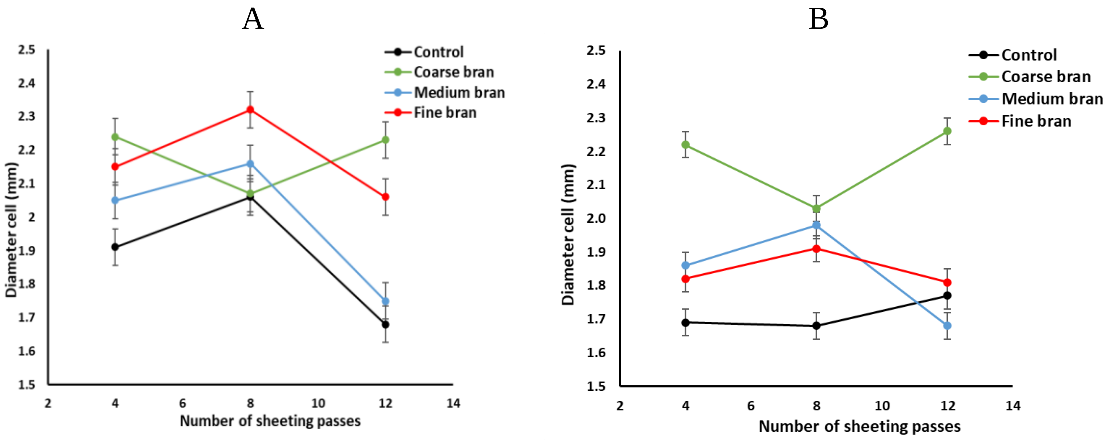


Figure 7.16 Average diameter cells of final baked loaf containing 10% of Fine, Medium and Coarse bran, compared with loaf control, the doughs were mixed for 3 minutes in the Tweedy mixer, then sheeted at a roll gap setting of 6 mm (figure a) 12 mm (figure b) for 4, 8 and 12 sheeting passes.

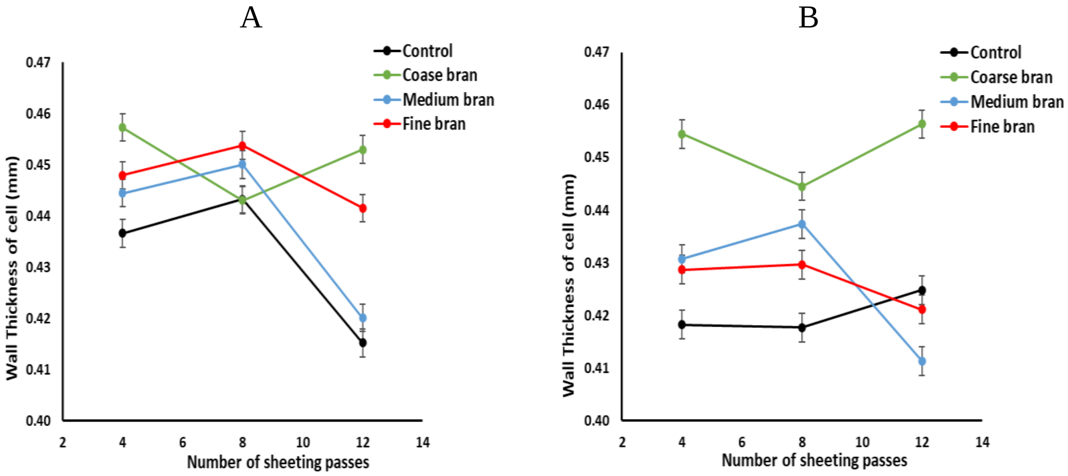


Figure 7.17 Average wall thickness of final baked loaf containing 10% of Fine, Medium and Coarse bran, compared with loaf control, the doughs were mixed for 3 minutes in the Tweedy mixer, then sheeted at a roll gap setting of 6 mm (figure a) 12 mm (figure b) for 4, 8 and 12 sheeting passes.

	Control	10% Fine bran	10% Medium bran	10% Coarse bran
Number of cells	**2559**	**2342**	**1964**	**1692**

Figure 7.18 Effects of sheeting on crumb structures containing 10% of Fine bran, Medium bran and Coarse bran, compared with loaf control, the doughs were mixed for 3 minutes in the Tweedy mixer, then sheeted at a roll gap 12 mm 8 sheeting passes. : Showing crumb structures crumbs are serialized from the highest number of cells to the lowest number of cells. The images were enlarged and zoomed out to show the crumb structure clearly.

Rheology and aeration interact during the breadmaking process again but in this time during sheeting and based on the results of this study. The interactions occur in the same sequence of Figure 1.2 in chapter 1 (section1.3). Figure 7.19 shows a representation of the breadmaking process that highlights these interactions. As mentioned in Figure 1.2 in section (1.3) most of the control of bread quality occurs at the mixing step (what dough formulation to use; what mixer to use; and how to operate the mixer) (Campbell & Martin, 2012, 2020). In addition, the roll gap of sheeter, the number of sheeting and dough formulation with bran (Bran particle size and its level) are also the keys used by a baker in preparing to manufacture bread during the sheeting process as shown in Figure 7.19.

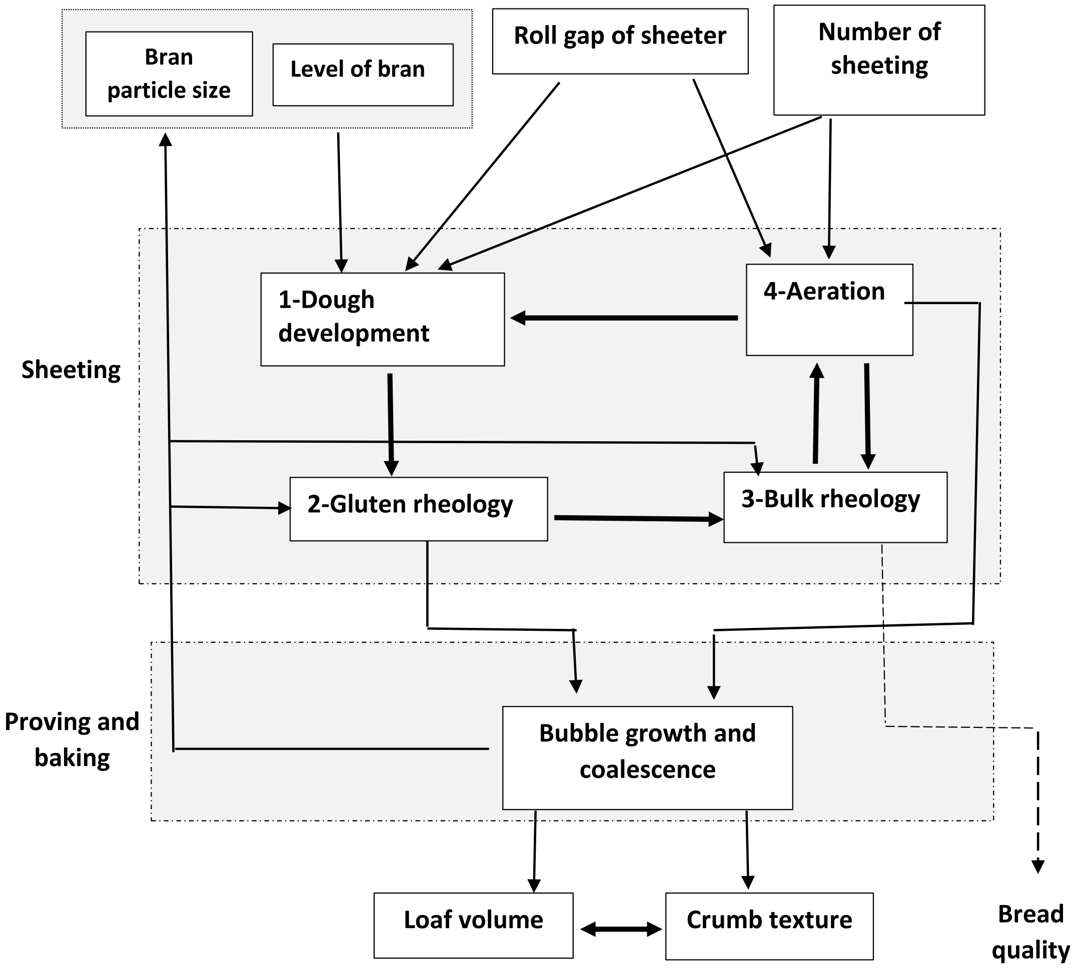


Figure 7.19 Effects of particle size and level of bran, roll gap and number of sheeting, on interactions between aeration and rheology during sheeting, proving and baking.

7.4 Summary

This chapter has presented a series of studies aimed at deepening understanding of the relationships between dough development by sheeting and bread quality as affected by bran level and particle size.

For all dough formulations with bran, in contrast to the Control (without bran), dynamic dough density tests showed that as the number of sheeting passes increases, the maximum expansion and the springback both increased from 4 to 8 passes, then decreased at 12 sheeting passes. This gives a clear indication of the effectiveness of sheeting on dough development, and a basis for quantifying development and optimising sheeting processes and maximising their benefits for bread quality and energy efficiency. Bran has a detrimental effect on the dough expansion, with Fine bran particles more damaging than Medium and Coarse bran. However, sheeting can enhance the ability of bran-enriched doughs to expand, potentially offering a route to counteract the damaging effects of bran on gluten development, although over-sheeting becomes more of a risk with bran in the formulation. The effects of bran on expansion capacity during proving were translated into effects on final baked loaf volume.

The C-Cell was used to quantify the quality of final baked bread in terms of the number, diameter and wall thickness of gas cells, and the volume of bread was measured using the EinScan 3-D scanner. The benefits of sheeting for bread quality were evident as increases in the volume of final loaves. The effects of sheeting on expansion capacity during proving were translated into effects on final baked loaf volume. These positive effects are due to the effects of sheeting on gluten development, which enhances expansion capacity during proving and gives more and smaller gas cells in the bread.

Chapter 8. Effects of bran on dough development in the Mixolab 2

8.1 Introduction

When bran is added to bread dough formulations, the water level of the dough needs to be adjusted in order to maintain the processability of the dough and to give high quality bread. However, the precise amount of water adjustment is not easy to determine. In the work presented so far, a standard adjustment to the water absorption, equal to half the level of bran substitution, has been applied, based on the guidance of previous work (Campbell et al., 2008a, b). Towards the end of the current project, the opportunity arose to use a Chopin Mixolab to investigate the effects of bran on dough processing, and in particular, to use this instrument to determine the appropriate water absorption adjustment.

The rheological properties of dough are determined through factors such as mixing, extension and warming of the dough as well as the quality of flour. However, these properties are changed by increasing the amount of the dietary fibres, whereby the main source represents the bran of the cereals. In turn, it works to weaken the gluten network, resulting in serious problems in the quality of the bread, such as a lower volume and a crumb that is tense and non-elastic, and changes in smell and taste depending on the type of the fibre and of the bread (Sinani, 2009; Xhabiri et al., 2016). There is some equipment produced by Brabender which is used in determining the rheological properties such as Farinograph that indicate the information related to the flour quality during mixing, Extensograph that indicates information related to pulling and resistance of the dough. Recently, the Chopin Mixolab is used for the same purpose and determining the quality of proteins and starch at the same time (Xhabiri et al., 2016).

This chapter presents a study of the effects of wheat bran on the dough behaviour during mixing. The effects of the level and particle size of bran on water absorption were investigated using the Mixolab 2. In addition, a range of properties reported from the Mixolab curve, Mixing Index, Gluten Index, Viscosity Index, Amylase Index and Retrogradation Index, were also considered in relation to the effects of the level and particle size of bran in the dough formulation.

8.2 Materials and methods

This section details the materials, equipment and methods used to investigate the effects of different levels and particle sizes of wheat bran on behaviour of flour during mixing and heating using the Chopin Mixolab 2.

8.2.1 Mixolab 2

The Chopin Mixolab 2, as described in Chapter 5, was used in this study to measure quality parameters for wheat flour enriched with different levels and particles size of bran. The characteristics of dough were determined using the Mixolab 2 standardized protocol (Chopin Technologies, ICC N 173, AACC54 - 60.01 and NF V 03 - 764). The parameters obtained from the Mixolab included the percent of water required for the dough to produce a peak torque of 1.1±0.05 N m (water absorption, %), the time to reach peak torque before the heating phase [C1, dough development time, min], the elapsed time that the torque remained at 1.1 N m (stability, min), torque following starch gelatinization (C3, N m), stability of the hot formed gel (C3 – C4, N m), and torque following cooling and starch retrogradation (C5, N m).

After selecting the specific protocol, an initial water absorption is estimated, and then the Mixolab automatically calculates the required amount of flour. After calibration is finished, the test is started. At 8 min of operation, which is the period for calculating the water absorption, if the target torque (1.1 N m) has not been reached, the program advises (using a pop-up window) an adapted water level with which to carry out another test.

8.2.2 Effects of bran particle size, level, on the water absorption of flour

The same Coarse, Medium and Fine brans were used as in Chapter 7. Doughs with different levels and particle sizes of bran were mixed in the Mixolab for 8 minutes to measure the water absorption, and then mixing was continued for a total of 45 minutes, with heating and cooling of the dough, to complete the test. Thus, the total number of trials was ((three bran sizes) × (three levels) plus a Control) × three replicates = 30 trials. This experiment was therefore conducted over three days, with ten trials per day. The three days covered three different percentages of bran (5, 10 and 15%), with three particles size of bran (Coarse, Medium and Fine) used each day in triplicate, in addition to the Control. The 10 trials within each day were undertaken in a random order.

8.2.3 Statistical analysis

Three Mixolab tests measurements were performed for each sample. A pooled standard deviation and ANOVA were calculated using Microsoft Excel. Error bars are presented as ±1 standard deviation of the mean.

8.3 Results and Discussion

8.3.1 Effects of bran particle size and level on water absorption

Figure 8.1 shows Mixolab curves for doughs containing Coarse, Medium and Fine bran at 5, 10 and 15%, compared with a Control flour with no bran. Looking closely, there is a difference in the time required to obtain C1 between the bran particles size. Reducing the size of the bran (Fine and Medium bran) causes C1 to be reached more quickly compared to the bran with large size (Coarse bran). The development time (C1) is increased with increasing the level of bran for the three sizes of bran.

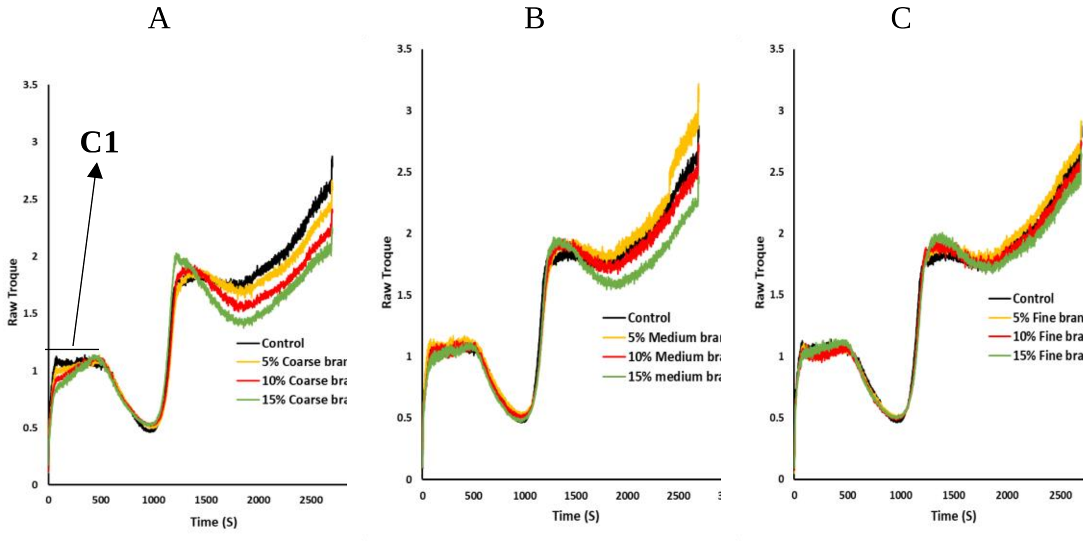


Figure 8.1 Curves for doughs containing Coarse (A), Medium (B) and Fine bran (C) at 5, 10 and 15%, compared with a control flour with no bran.

The effect of bran particle size and level is more evident in Figure 8.2, which shows the average development time and the stability time with the addition of bran into white flour, compared with the control. The development time (C1) of the dough increased significantly ($p < 0.05$) with the addition of bran and the stability time decreased, with the smallest changes occurring for Fine bran and the largest changes for Coarse bran. The longest time to peak development (C1) was for the dough with 15% Coarse bran, which also exhibited a sharp drop in the stability time. Reduction of bran particle size and level contributes to decreasing the development time and increasing the stability time. This agrees with Xu et al. (2018) who also found that the addition of coarse bran into white flour increased the Mixolab development time (C1) and decreased the stability time. This is because of the longer period of water absorption which is required by the coarse bran (Liu et al., 2016). Xu et al. (2018) also found increased dough development time of wheat flours with medium and fine bran. Comparing to the dough with coarse or medium-ground bran, superfine grinding of bran could increase the stability time of dough, which might result from the faster absorption of water by wheat bran of finer particle size (Penella et al., 2008).

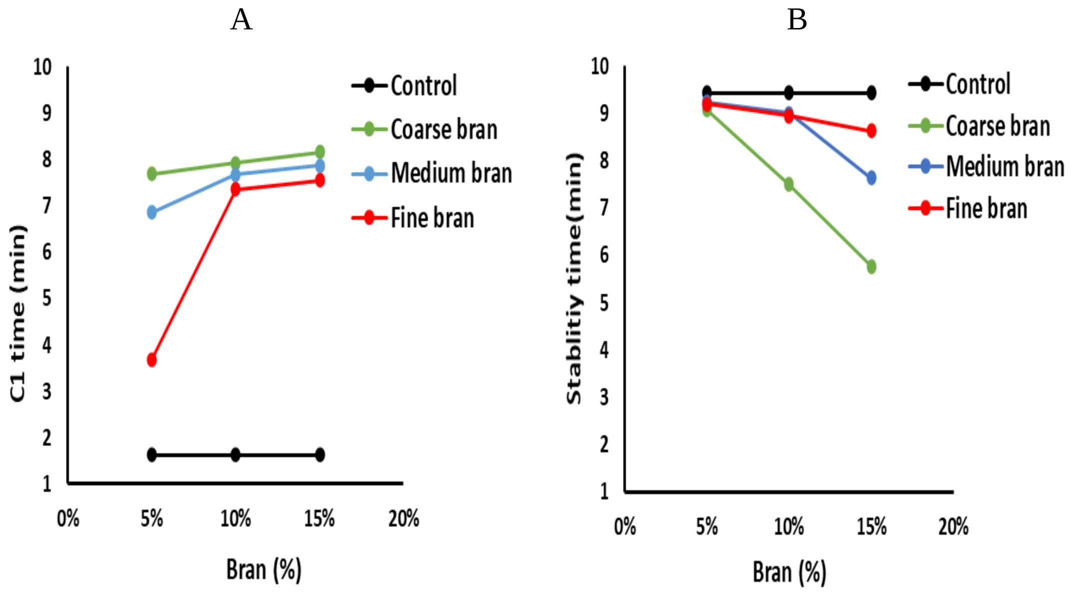


Figure 8.2 Mixolab development time (C1)(A) and stability time (B) of doughs containing 5%, 10% and 15% of Fine, Medium and Coarse bran compared with a Control flour with no bran (Error bars are not shown in the figure, as they were smaller than the symbols used).

Figure 8.3 shows the water absorption of the doughs with different size particles (Coarse, Medium and Fine bran) and levels of bran (5%, 10% and 15%) determined using the Mixolab instrument, along with the Control. The water absorption significantly ($p < 0.05$) increased with the increasing level of bran, and reduction of particle size to Medium or Fine at the level 5% and 10%. At 15% bran there appears to be no significant change in water absorption between the three sizes of bran.

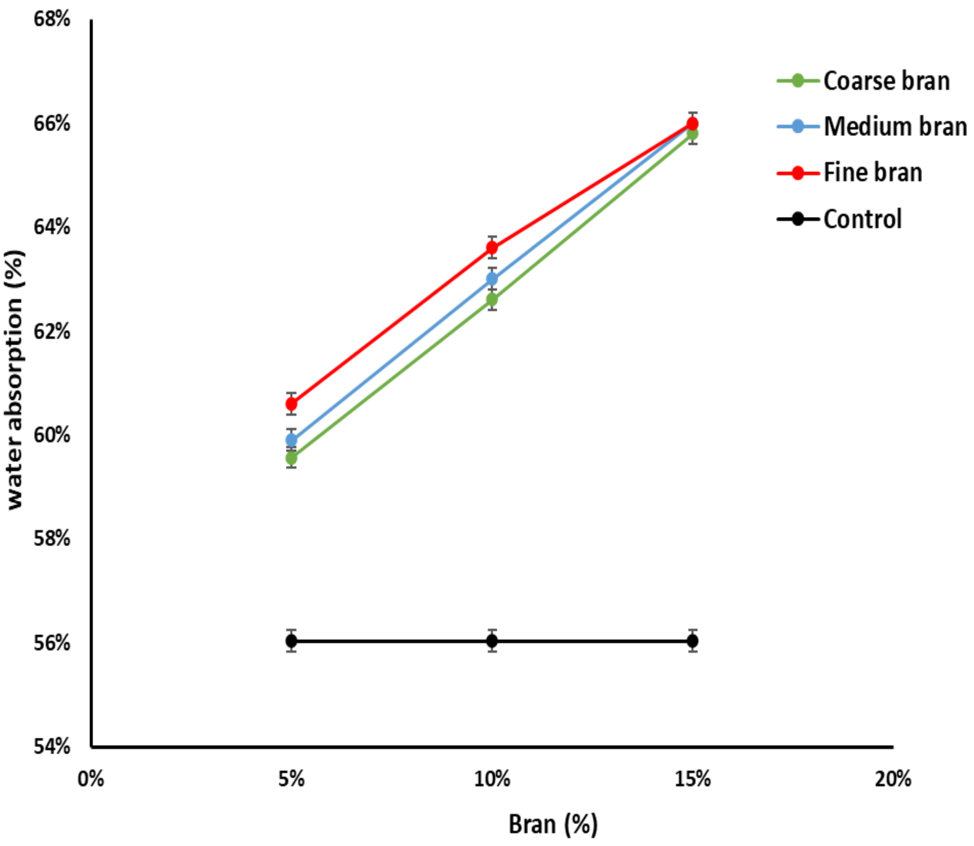


Figure 8.3 Water absorption of doughs containing 5%, 10% and 15% of Fine, Medium and Coarse bran, compared with a Control flour with no bran.

Table 8.1 compares the WA determined by the Mixolab results with WA values used in the studies presented in previous chapters. The previous guideline used in the current study was to increase water absorption by half the bran level, irrespective of particle size (Campbell et al., 2008 a, b, c) as described in Section 5.3.2. ANOVA analysis showed that there are no significant differences (*P*-value ≥ 0.05) between them, the Mixolab results suggest that this previous guidance gave an underestimate of the required adjustment. Thus, for example, for a 15% bran level, the previous guidance indicated an increase in water absorption of 7.5%, while the Mixolab suggests an adjustment of 10%.

The Mixolab results also suggest that the adjustment needs to be greater for finer bran particles.

Table 8.1 Comparison between Water Absorption increase compared with Control, calculated by Mixolab and by previous guidance of half the bran level.

Dough formulation	Water Absorption increase (%)						*p*-value		
	Mixolab results			Previous guideline					
	5%	10%	15%	5%	10%	15%	5%	10%	15%
Coarse bran	3.57	6.60	9.80	2.50	5.00	7.50	1.07	1.6	2.3
Medium bran	3.90	7.00	10.00	2.50	5.00	7.50	1.4	2	2.5
Fine bran	4.60	7.60	10.00	2.50	5.00	7.50	2.1	2.6	2.5

Large bran particles have been found to take up more water in comparison with smaller particles, based on the traditional water retention capacity, the swelling capacity, and Enslin water absorption tests (Jacobs et al., 2016). In the current study, the water absorption of Fine bran particles recorded higher values at levels of 5 and 10% bran compared to the Coarse bran. This agrees with some studies which reported that a reduction of bran particle size contributes to increase in dough water absorption (Cai et al., 2014; Niu et al., 2014; Xu et al., 2018). However, other studies found that water absorption of dough was independent of bran particle size (Jacobs et al., 2016; Zhang & Moore, 1997). This is similar to the results of this study at level 15% bran, where there was no difference in water absorption between the different particle sizes of bran. The reason for the agreement may be due to the fact that the current study used three bran levels, unlike the other studies that used just a 15% level of bran (as this is close to the natural level of bran in wholemeal flour). Liu et al. (2016) found that reducing bran particle size contributes to decreasing the water absorption of dough. These inconsistent results might be caused by the different milling procedures used, bran particle size ranges, different instruments used and end products made. In addition to the damaged starch content, it may be that the reason for increased absorption of water is the increase in the surface of the milled bran, which contributes to the rapid increase of water absorption in the short mixing time (Campbell et al., 2008a). This is reflected in the longer development time (C1) for doughs containing Coarse bran compared with Medium or Fine bran (Figure 8.2A).

8.3.2 Effect of bran particle size and level on the quality parameters of the flour

Figure 8.4 shows the values of Alpha, Beta and Gamma during the heating phase of the dough; these values indicate the rate at which torque changes during transitions caused by heating and subsequent cooling. Addition of bran into white wheat flour resulted in an increase the index of protein weakening (Alpha) which is calculated from slope of the curve between the end of period at 30°C and C2, the lowest point following the onset of heating. This negative slope indicates how application of heat initially reduces the viscosity of the dough, prior to the increase caused by the onset of starch gelatinisation and protein denaturing at higher temperatures. As shown in Figure 8.4A, the index increased (i.e. became less steeply negative) for Coarse and Fine bran. Medium bran gave the lowest Alpha values, which were not much different than for the Control flour. This is in line with observations from the previous chapter that Medium bran seems to affect dough behaviour less than either Coarse or Fine bran.

Figure 8.4B presents Beta values, which are calculated from the slope of curve between C2 and C3 and indicate the increase in viscosity caused by starch gelatinisation. Addition of bran at 5% seemed to have no effect on the rate of starch gelatinisation for Coarse and Medium bran, while Fine bran gave a lower value of Beta, suggesting a slowing of starch gelatinisation. At higher levels of 10 and 15% bran addition, all sizes of bran increased the rate of starch gelatinisation by similar amounts. The results are a reflection of two separate, and to some extent counter-acting, effects of bran – on the one hand, there is more water available, but on the other hand, this is bound up in the bran and released on application of heat at a rate that depends on the particle size. In addition, with substitution of bran for flour, there is simply less starch to gelatinise, and there may be additional enzyme activity.

Figure 8.4C shows values of Gamma, which reflect the decrease in viscosity arising from amylase degradation of starch, calculated as the negative slope of the curve between C3 and C4. Amylase values reflect the hot-gel amylase activity, which decreased (became more steeply negative) with increasing the level of bran, and in general more so for Coarse than for Medium and Fine bran, the latter indicating a lower amylase activity and a more stable starch gel. Compared with effects on the other parameters shown in Figures 8.4(A) and (B), bran appeared to have much greater effects on this part of the Mixolab curve.

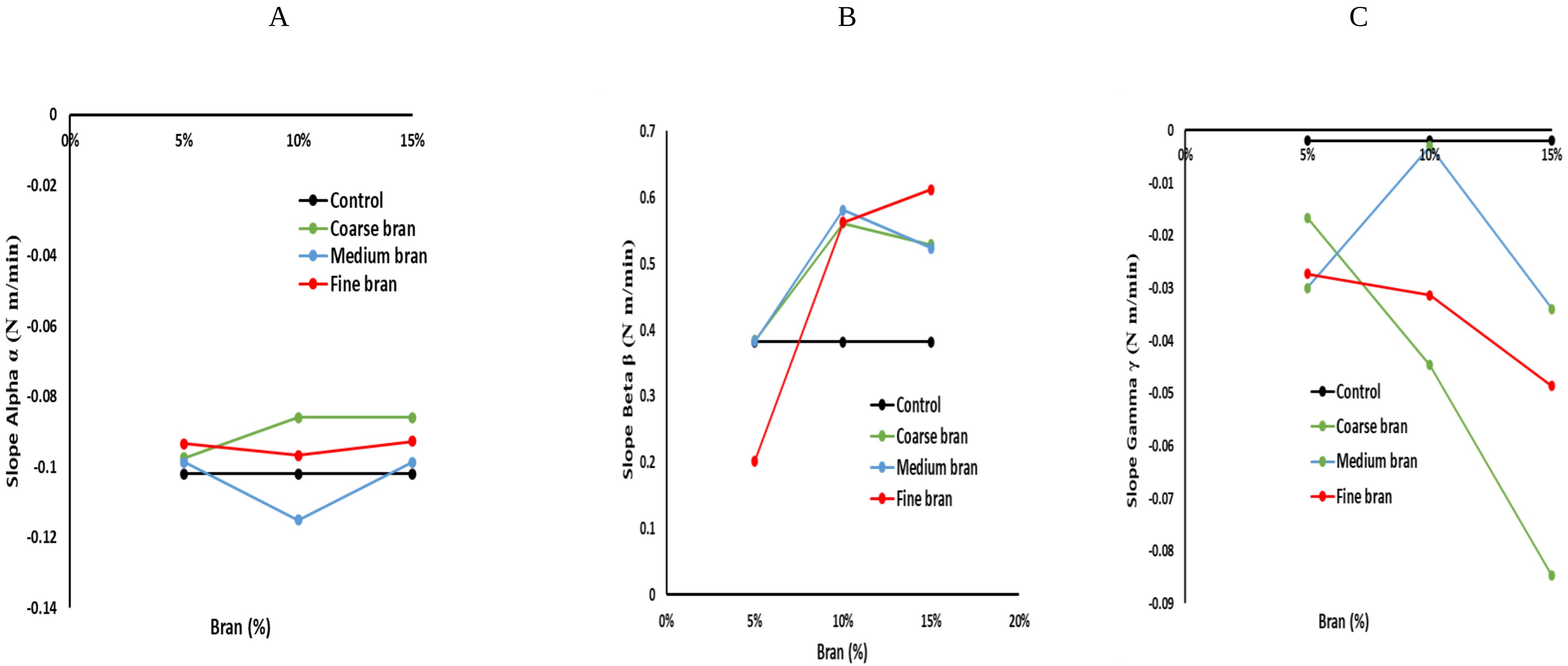


Figure 8.4 Values of Alpha (α) (A), Beta (β) (B) and Gamma (γ) (C) of dough containing Coarse bran, Medium bran and Fine bran at 5, 10, 15%, compared with control flour with no bran.

In the earlier work in this thesis, effects of bran on sheeting and on bread quality were investigated, adjusting the water absorption using the guidance of increasing WA by half the bran level, irrespective of bran particle size. The current chapter has shown that this guidance could be refined by using the Mixolab, which would make studies on the production of wholemeal breads using sheeting to develop the dough more precise, but is unlikely to alter the broad relationships that have been identified in the earlier work.

Generally, the addition of bran has a clear effect on water absorption. This effect increases with the increase in the level of bran and the decrease in its particle size, as also reported by Cai et al. (2014), Niu et al. (2014) and Xu et al. (2018). Water retention by bran on a macroscale is ascribed to filling of void spaces in between bran particles, which arise from random stacking of bran particles (Jacobs et al, 2015). The lowest absorption was recorded with the Coarse bran, reflecting the longer time required to absorb water by large particles compared to smaller particles (Liu et al., 2016), which results in an increase in the development time (C1 time) of the dough and decrease in the stability time. This agrees with Xu et al. (2018) who also found that the addition of coarse bran into white flour increased the development time of dough and decreased the stability time. The long development time of the dough with coarse bran is attributed to the fact that coarse bran particles need more time to absorb water than fine bran, and also releases its water more slowly, due to the lower surface area (Penella et al., 2008). This may agree with the results of the previous chapter, which showed that Coarse bran has a high effect on the dough development (lower dough expansion and lower springback of dough), resulting a small volume for the final bread with an open crumb structure. In addition to the previously mentioned reasons, perhaps one of the reasons for this effect is that the Coarse bran needs a longer time to absorb water, which in turn increases the period of dough development and decreases the stability time of the dough. In addition to the gluten quality, the amount of water absorbed by flour is responsible for the optimum development of the dough (Morton, 1987). Fine bran gives a higher water absorption than coarse bran, as measured using a Farinograph. This observation is attributed to the fact that the specific surface of fine bran is increased and exposed to hydroxyl groups (Cai et al., 2014; Noort et al., 2010; Penella et al., 2008). The Fine bran particles, which were estimated in the range of 174 µm in the current work, decreased the dough development time and increased the stability time. This agrees with a study by Liu et al. (2016) who found that a reduction of particle size (from ~175 µm to ~130 µm) increased the Mixolab stability time for three classes of U.S. hard whole wheat flours. They also found that fine bran particles seem to have a less destructive effect on gluten network formation in dough than coarser particles. Although, in the previous chapter, Fine bran has a higher effect than Coarse bran on the dough development (Expansion of the dough and volume of final loaf), the development time, and the stability time of Fine bran dough are similar to the Control with no bran. Perhaps this corresponds to the results of the previous chapter, which related to the C-cell results, where the Fine bran gave the results of crumb structures (number of cells, diameter and wall thickness of cell) similar to the Control with no bran, especially at 12 mm roll gap. Medium bran was moderate at the development time and stability time, as it was between Coarse and Fine bran. This also agrees with the results of the previous chapter related to the C-cell, where the Medium bran gave the results of crumb structures as between Coarse and Fine bran.

The Mixolab values of Alpha, Beta and Gamma also showed effects when adding bran, indicating effects on weakening of the protein network during heating and on the dynamics of starch gelatinisation and degradation. The small effect on Alpha values, which reflect protein weakening, suggest an interaction between the bran and the gluten network, with Fine and Coarse bran disrupting the gluten more than Medium bran.

Perhaps due to the intricate competition between the bran and starch in water absorption, no clear patterns were observed in the effects of bran particle size and level on Beta values, which indicate rate of starch gelatinisation. However, Xu et al. (2018) found addition of bran into white wheat flour resulted in lower C3 values, which is the maximum torque during the Mixolab heating stage and represents the degree of starch gelatinization. This could be attributed to lower starch content or high enzyme activity in the bran. It showed a significant increase in the values of C3 with reduction of wheat bran particle size by medium or super-fine grinding. By contrast, Gamma values were more severely negative with the addition of bran, especially Coarse, and this indicates an enzymatic breakdown of the starch matrix, suggesting enhanced enzyme activity contributed by the bran (Bonnin et al., 1998; Poutanen, 1997).

8.4 Summary

This chapter has presented a study aimed at deepening understanding of the effect of bran level and particle size on the flour properties such as water absorption, stability time, development time of the dough and other parameters reported by the Chopin Mixolab 2.

Mixolab measurements showed that, compared with the Control, the water absorption increased with the increasing the level of bran, and with reducing the bran particle size. Reduction of bran particle size and increasing bran level also decreased the development time and increased the stability time.

Mixolab results also showed that the addition of bran affects the rate of protein weakening on heating (Alpha values), the rate of increase of viscosity due to starch gelatinisation (Beta values) and the rate of amylase degradation (Gamma value). Alpha values were largely unchanged at 5% bran and increased (became less steeply negative) at higher levels, with Medium bran giving the lowest index, compared to Coarse and Fine bran. Beta values were higher with addition of bran beyond 5%, and similar for all particle sizes, reflecting complex interactions between water partitioning between bran and starch. Gamma values became more sharply negative with bran addition, particularly for Coarse bran, suggesting more rapid enzymatic breakdown of the starch matrix.

The next chapter concludes the thesis by summarising the main findings from the current work and presenting recommendations for further research in this area and for industrial exploitation of the findings.

Chapter 9. Conclusions and Recommendations for future work

9.1 Progress made in the current work

The main objective of this research was to study the effect of sheeting regimes (different roll gaps) on the development of the dough, for a range of dough formulations, including effects of bran (of Coarse, Medium and Fine particle size, at flour substitution levels of 5, 10 and 15%) on dough aeration and development. A distinctive aspect of the work was the way it considered the physical behaviour of bubbles within the dough and used the novel Dynamic Dough Density (DDD) measuring system to study dough expansion during proving. The effects of sheeting on the volume and structure of final baked loaves were also evaluated. The water absorption of the flour with or without the bran was also investigated.

Static density tests showed that gas is removed to some extent from doughs during sheeting, in agreement with previous reports. The extent of unyeasted dough degassing increased with the number of sheeting passes, followed by an apparent decrease in density caused by gas entrainment or changes to the dough matrix as development progressed further.

Dynamic Dough Density tests showed that as the number of sheeting passes increased and the roll gap decreased, the minimum density decreased, indicating an increase in the maximum expansion capacity of the dough. There is a difference in values of minimum density of dough between the doughs mixed in the Tweedy mixer and those mixed in the Majorpin mixer and then sheeted for different numbers of passes. It is clear that, overall, the degree of development achieved by sheeting is greater than that achieved by mixing using either mixer. This gives a clear indication of the effectiveness of sheeting on dough development, and a basis for quantifying development and optimising sheeting processes in order to maximise their benefits for bread quality and energy efficiency.

Bran has a detrimental effect on DDD expansion, with fine bran particles more damaging than coarse bran. However, sheeting enhances the ability of bran-enriched doughs to expand, potentially offering a route to counteract the damaging effects of bran on gluten development. Increasing the amount of wheat bran in the formulations reduced the expansion capacity and springback of the dough, more so for the Fine and Coarse bran samples than for Medium bran samples, suggesting that it is possible for bakers to use an optimum bran particle size to minimise the damaging effects of bran.

Sheeting had a positive effect on final loaf volumes and the softness of the crumb, up to a point, after which prolonged sheeting appeared to damage the gluten and reduce loaf volumes. The effects of sheeting on expansion capacity during proving were translated into effects on final baked loaf volume. These positive effects are due to the effects of sheeting on gluten development, which enhances expansion capacity during proving and gives more and smaller gas cells in the bread, as estimated by the C-Cell bread analysis system.

Water absorption increased with the increasing the level of bran, and with reducing the bran particle size. Reduction of bran particle size with increasing bran level also decreased the development time and increased the stability time. Inclusion of bran in the dough formulation appeared to affect other parts of the Mixolab curve related to protein weakening and starch gelatinisation during heating, and enzymatic starch degradation.

In general, the current work applied a range of new techniques to demonstrate and clarify the benefits of sheeting on dough development and baked loaf quality, and investigated for the first time the interactions between sheeting and bran, with a view to enhancing the quality and consumer acceptability of wholemeal breads by exploiting the superior gluten development that can be achieved using sheeting. Regardless of the bread type (white or brown), bakers and manufacturers of bread also can be achieved using sheeting, as it is less costly for energy than some other technologies.

9.2 Recommendations for future work

In this study, the effect of sheeting on the quality of the final bread was estimated by the C-Cell. The promising results showed the extent of the effect of the number of sheeting passes and the roll gap on the texture of the loaves in terms of the number and distribution of cells and their wall thickness. It is recommended for future studies to focus more on the aeration of the dough and bubble behaviour as affected by sheeting, using microscopic imaging techniques and X-ray microtomography to measure the bubble size distributions in dough. Such studies would give a detailed insight into the precise effects of sheeting on the bubbles size distribution, which is challenging especially with the addition of fibre ingredients. Such methods are a relatively new that would be valuable to apply to such studies. In this way, both the aeration of the dough and its rheology as affected by sheeting will be understood; these two aspects of dough interact to create bread structure and quality, and understanding both of them together will give a firm basis for a more complete understanding of sheeting and how best to exploit it in breadmaking processes.

The effect of sheeting on the dough development was studied using the DDD system. Promising results were obtained that are able to quantify the effects of bran and processing on the ability of gluten in the dough to expand and retain gas. Additional complementary techniques that would help to construct a fuller explanation of behaviour of dough and its development would include the Stable Microsystems Dough Inflation System, an attachment for the Stable Micro Systems Texture Analyser, which uses an inflating bubble of dough to quantify dough rheology under large strain deformation reference. It is expected that this will provide complementary insights to that provided by the DDD test and would be a useful tool to apply to understand more fully the effects of sheeting on dough rheology with and without bran. As well as it is recommended some sensory analysis of bread rich in bran which is made using sheeting as part of breadmaking process. The results of this thesis showed an increase in the expansion of the dough without bran up to 12 passes which is the highest number of sheeting passes used in this study. Extending the work to determine the maximum number of sheeting passes that achieve the highest dough development is important to fully understand the potential of sheeting for enhancing dough development and bread quality.

Given the relative lack of studies on the sheeting stage of the breadmaking process, the results obtained in the current study add to the body of knowledge and point to several other possible studies for further research and for greater adoption of this promising operation by the bread industry. In particular, sheeting has great potential to increase the quality of bread rich in bran, which will enhance the consumer's desire to consume fibre rich bread and to obtain its many health benefits. In addition, sheeting is much more energy efficient than mechanical dough development, able to develop doughs using only about 15% of the energy of high-speed mixing to achieve similar levels of development and bread quality (Kilborn and Tipples, 1974). Given the much greater importance these days of reducing energy usage in industrial processing, sheeting is timely for offering the bakers a way of addressing this goal while also enhancing bread quality.

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Appendix 1. Calculation of water temperature to control final dough temperature

Assuming the major components of dough are the flour and water, an energy balance on dough mixing is:

Energy entering with the flour + energy entering with the water + energy added during mixing = energy exiting in the dough

$$\mathrm{m_f c_{pf} T_f + m_w c_{pw} T_w + WI = \left(m_f c_{pf} + m_w c_{pw}\right) T_{dough}}$$

where m_f and m_w are the masses of flour and water, respectively, c_{pf} and c_{pw} are the specific heat capacities of flour and water, respectively, T_f and T_w are the initial temperatures of the flour and water, respectively, and T_{dough} is the final dough temperature.

Taking a 100% flour basis with a specific heat capacity of around 1.8 kJ kg^{-1} K^{-1} and an initial temperature of 20°C, a water absorption of 60% with a specific heat capacity of 4.180 kJ kg^{-1} K^{-1}, a work input of 40 kJ kg^{-1} of dough, and a target temperature of 30°C, and basing calculations on 1 kg flour, gives

$$1 \times 1.8 \times 20 + 0.6 \times 4.18 \times \mathrm{T_w} + 40 \times 1.6 = (1 \times 1.8 + 0.6 \times 4.18) \times 30$$

$$\mathrm{T_w} = \frac{129.24\text{-}36\text{-}64}{2.508} = 11.7℃$$

In the current work, it was not possible to measure work input accurately. It was assumed that a work input of 40 kJ kg^{-1} was delivered in around three minutes in the Tweedy mixer, and that shorter mixing times delivered proportionally smaller work inputs. The above calculations are not precise, but are good enough to allow a final target temperature of 30 ± 1°C to be achieved.