Bakery Products Science and Technology

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Second Edition

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Preface to the Second Edition

Bakery products, especially bread, have a long history and they form an important part of the diets of humans around the globe. Bakery products are not only popular in traditional markets such as Europe, but they are also gaining popularity in emerging markets. For example, Euromonitor International recently reported that China's market for industrial baked goods was valued at US$25.4bn for 2013, up from US$19.6bn in 2012.

Meanwhile, today's consumers are increasingly conscious of health issues, so producing high-quality bakery products presents both a challenge and an opportunity. While there is no dispute that bakery products contain a high amount of carbohydrate and some may also contain gluten and high levels of fat and sugar, they can also be a source of wholesome food and balanced nutrients. Producing new types of bakery products or reformulating existing ones to increase their nutritional value or raise their nutritional profile is likely to remain a trend for the foreseeable future.

Since the publication of the first edition of this book in early 2006, progress in the science and technology of baking and bakery products has done much to address these and other challenges. Therefore, the second edition provides a timely update and expansion to the previous edition. The book consists of 42 chapters that are grouped into 7 parts:

1. Introduction to baking and bakery products;
2. Characterization and properties of important types of flours for bakery products, including those from wheat, rye, rice, barley, maize, sorghum, millet, and other grains;
3. Major baking ingredients such as water, yeast and other leavening agents, ascorbic acid and other redox agents, sugar and sweeteners, lipids, egg, dairy ingredients, enzymes, and other functional additives;
4. Science and technology of bakery production with dedicated chapters on mixing and dough making, fermentation, baking, and packaging. Also included are shelf-life prediction, process optimization and control, and sensory and nutritional attributes of bakery products. Specific issues such as rheology, browning, and functional bakery products are also covered;
5. Manufacturing of a variety of bread products including yeast bread, sourdough, frozen dough, par-baked bread, and steamed bread, as well as their quality control issues;
6. Other selected bakery products such as cakes, biscuits, pastries, pretzels, bakery products from unconventional flours, and dietetic bakery products; and
7. An overview of specialty bakery products from around the world as well as an in-depth analysis of bakery products from selected countries including China, Italy, Mexico, and Turkey.

Despite every intention to provide a comprehensive reference book on baking science and technology, we appreciate that it is not possible to claim that this book represents complete coverage. Nevertheless, we hope it serves as an essential reference on the latest knowledge and technologies for professionals in the baking industry, academia and government bodies, as well as for undergraduate and postgraduate students in their study and research related to baking and bakery products.

We thank the contributors, all respected professionals from industry, government, and academia, for sharing their experience and expertise in their particular fields. The 65 authors are from 21 countries and have a diversity of expertise and background that cover the whole spectrum of the science, technology, and engineering of baking and bakery products.

We also express our sincere thanks to the five associate editors who are domain experts from five countries, for their dedication to producing a book of the highest quality possible, and the editorial and production teams at Wiley Blackwell for their efforts, advice, and professionalism.

We truly wish that you enjoy the book and find its contents informative and beneficial to your work, research, or study.

Weibiao Zhou and Y.H. Hui

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Introduction

If a number of different consumers were asked what qualities they looked for in a loaf of bread they would all have different views. It is soon recognized that bread quality is very much an individual perception. The subject of quality in bread is therefore a contentious issue. Quality means different things to different people, and no two people share the same opinion about a particular type of bread. However, cereal scientists and technologists are able to identify certain characteristics of each style of bread and determine the attributes that add to its quality and those that detract from it. In this chapter the issue of bread quality is tackled from the European perspective, and the factors that are considered to be important in the range of bread types that are popularly consumed in the United Kingdom and the rest of Europe are examined.

Appearance is the first visual assessment of a loaf, and key factors include the volume (size) of the bread as well as the color, particularly that of the crust and the shape of the loaf. The consumer is also likely to give the loaf a squeeze to obtain an idea of the softness so that a quick judgment can be made of the freshness. Crust color and softness are probably the two key issues consumers use to make their choice at the point of sale. There are various faults in the external appearance of loaves that can be readily identified as unacceptable. In this chapter, the more commonly encountered faults are described and, where possible, illustrated, and information is provided for remediating such faults when they occur.

Important quality issues arise from the style of bread under consideration. For example, a key factor for sandwich-type bread would be the uniform distribution of small-sized bubbles, which give the bread crumb its characteristic appearance and the physical strength to allow butter to be spread over the surface. For French baguettes, it is the crisp, flavorful crust that contributes most to eating quality, paired with the crumb being open and irregular in appearance. For these two bread types the production methods are essentially the same; the process must create the appropriate number and sizes of gas bubbles in the dough and ensure that they survive during subsequent processing. The process of creating and controlling bubble structure therefore makes a fundamental contribution to bread quality, and this chapter deals with the key mechanisms of structure control available to the baker as well the choice of ingredients, formulations, equipment, and processing methods that affect final product quality.

Bread quality changes with time. This is true for all types of bread, and storage generally leads to loss in quality. There are various factors that combine to make the bread go stale and eventually become unfit to be sold. The roles of ingredients and methods of mixing have a large impact on the shelf-life of bread. Staling is one of the main processes that causes bread to lose quality. Staling is a complex process and is related to changes in the starch. It is also referred to as chemical staling. Key factors involved in bread staling are examined in this chapter, and methods are outlined to explain how the processes leading to deterioration in quality can be slowed down to prolong the perceived freshness of bread.

Role of dough processing and bread quality

The style of bread dictates how the mixing, processing (molding), and baking are carried out. One would not want to produce French baguettes with a close crumb structure, and of course one would not want to produce an 800 g four-piece loaf with an open crumb structure like a baguette.

Whether making a four-piece or single-piece bread, the aim is to achieve the desired shape without causing damage to the bubbles that have been carefully developed during the mixing stage. Ninety percent of the final bread quality is achieved during mixing, so it is important to make sure processing continues to improve quality and avoids unnecessary damage. After mixing, the dough goes through several processing stages that change the shape of the dough and reorient the bubbles.

After dividing, the dough piece generally passes through a "rounding" stage, sometimes called first mold, and this stage uses equipment such as a conical molder to achieve a spherical dough piece ready to be passed through the final molder. After an initial resting period (intermediate proof), the dough piece moves to the final molder, which can be broken down into four sections (a sheeting stage, curling chain, pressure board, and guide bars), all of which influence the shape and length of the dough piece coming out of the end of the final molder.

Faults in loaf crumb structure, such as discolored coarse patches, streaks, and variations in softness are not uncommon in modern bread making. Many combinations of raw materials and dough processing stages can influence the occurrence of such faults, but they have a common origin. They are the direct result of instability in the structure formed during mixing and/or subsequent damage to the bubble structure during molding.

Dough mixing systems

Bulk ferment systems Bulk fermentation doughs account for only around 1% of the bread produced in the United Kingdom, but they are still widely used in other European countries. The main reason the process is not used widely in the United Kingdom is the time required to develop the dough and the open crumb structure associated with bulk-fermented products. Before the dough can be divided the following steps must occur:

- All the ingredients must be mixed to a homogeneous mass that can take up to 30 min in a low speed mixer.
- The dough must be given a bulk resting period that can be 1–16 h or longer. The bulk resting time will be dependent on the flour strength, dough temperature, and yeast level and, of course, the bread characteristics required. At this stage the bakery would also need a temperature-controlled room with sufficient floor space to store the dough.
- Halfway through the bulk fermentation, the dough is given a "knock-back," a remixing to control bubble formation and help ensure that the dough does not form a skin on the surface.
- After completing the bulk fermentation period the dough can then be processed in a manner similar to that used for no-time doughs.

No-time dough systems In a no-time dough system all the development is achieved in the mixer; after mixing is completed the dough is processed immediately, which would entail scaling, first molding, intermediate proof, final molding, final proof, and baking; from beginning to end the process can take approximately 2 h. Plant bakeries are the main users of no-time doughs (doughs in which all the development takes place in the mixing chamber), usually by means of the Chorleywood Bread Process (CBP) (Chamberlain and others 1962; Axford and others 1963; Chamberlain and Collins 1979).

In no-time doughs, the mixing process is critical to achieve optimum dough development and bubble structure. Typical examples of mixing equipment used to produce no-time doughs are shown in Figure 28.1.

When using a high-speed mixer, a watt-hour meter, not a timer, should be used to control the mixing. Variations in dough batch size and consistency affect the time required to achieve a given energy input. For example, a soft dough will achieve the correct energy input at a lower rate than a tight dough will, so working to time will cause real problems with consistency in dough development.

Intense mechanical work during mixing is an essential part of the rapid dough development and one means by which the bulk fermentation stage is eliminated. As the mixing blade moves through the dough, air bubbles are trapped and form the nuclei of the cell structure of the final product. The yeast cannot create the bubbles (Baker and Mize 1941), but it does expand the air bubbles with carbon dioxide, and the dough rises.

Figure 28.1 Mixers used for no-time dough production. Pressure-vacuum, left; spiral, right. Courtesy of Campden BRI.

The optimum level of mixing in the CBP varies according to the type of flour being used. An energy input of 11 Wh/kg has been found to be a suitable value to achieve optimum dough development for a wide range of flours. However, it is not unusual for bakeries to be mixing to 13 Wh/kg if they are using a particularly strong flour.

Important processing parameters influencing dough quality

Partial vacuum It is common practice with CBP batch mixers to mix the dough under a partial vacuum during the second half of the mixing. A vacuum level of about 0.5 bar absolute (0.5 bar below atmospheric pressure) produces bread with a finer and more even crumb cell structure than that of bread produced by mixing at atmospheric pressure or above in the same machine. Pulling a vacuum reduces the void fraction of air in the dough from approximately 8 to 4% at the end of mixing. The vacuum level should not be set too high or air will be prevented from being trapped in the dough, and a normal bubble structure will be absent, resulting in bread of very coarse structure.

When pulling a vacuum, at least 50% of the watt-hours used should be under atmospheric conditions, and the vacuum should be pulled halfway through the mixing cycle (Campbell and others 1998).

Positive air pressure Mixing at pressures greater than atmospheric increases the volume of air incorporated during mixing, which in turn increases the "average" size of the gas bubbles. Mixing under positive pressure allows the baker to choose the type of bubble structure required for different types of bread. A baguette, for example, should have an open and random crumb structure, and mixing under positive pressure allows this to be achieved.

When mixing under positive pressure, a slight reduction in the recipe water may be necessary, as more air in the dough tends to make the dough feel softer. By reducing the water a manageable dough consistency is achieved, and this will help the dough to process through the plant.

Pressure-vacuum mixers have the ability to work at pressures above or below atmospheric conditions in any number of sequences. For a typical sandwich loaf, mixing may be performed under pressure during the first half of mixing, ensuring full utilization of the ascorbic acid, before moving to a lower pressure to complete the process to achieve a close, even crumb structure in the baked bread.

Processing time Doughs made using the CBP are generally warmer and contain more yeast than those made in the bulk fermentation process, which means it is important to control processing times. Any delays in process will affect the crumb structure and create variability in the quality of the bread. Keeping this in mind, the baker should only produce batch sizes that can be processed through to final proof within 15 min. This is particularly important in the production of standard sandwich bread, which is characterized by a fine even crumb cell structure. If, however, you are producing bread that requires an open crumb structure such as rolls, buns, and in particular, French-style breads, longer processing times at the intermediate proof stage will help to achieve this; these times can be increased to 20–30 min.

Dough temperature Dough temperature is important no matter what bread production method is being used. Dough temperature influences the rate of both chemical and enzyme reactions. A low temperature slows the reaction rates, whereas high temperature speeds them up.

A dough temperature of 30–32 °C from the mixer is recommended for no-time doughs (Spiral and CBP). However, during the intense mixing of the no-time doughs, there is a significant rise in dough temperature; depending on the mixer, this can range from 10 °C up to 14 °C for high-speed mixers. Hotter doughs can be softer and stickier, which may limit the amount of water being added and will affect the yield per batch.

Dividing Dividing the dough needs to be done quickly and with as little stress placed on the dough as possible. Most dividers work by using the dough volume to give a specific weight; it is very important to present a consistent dough to the divider because otherwise underweight or overweight bread will be produced. This affects not only the weight of the dough but also the settings on the final molder, as these have been adjusted to accommodate variations in specific volume. It also affects the legal requirements for bread weight. Too large a volume of dough can cause excess pressure during molding and burst bubbles, which will lead to streaking in the crumb, as discussed earlier.

First molding Initial shaping of the dough before intermediate proof is used to provide a uniform shape that is then presented to the final molder. Uneven presentation of the dough piece to the final molder can result in loss of loaf volume, grey streaking in the crumb, and misshapen loaves that will cause problems during packaging.

Intermediate proof An intermediate proof period is recommended after dividing and first molding. This resting period allows the dough to relax before the final molding stage. If the dough is not allowed to relax there is a greater possibility of damaging the bubble structure and thus producing streaking and loss of volume in the baked loaf.

The length of this rest period is flexible. Generally speaking, it should not be shorter than 4 min or longer than 10 min for standard bread, but there are some bakeries that will have intermediate proof times as low as 30 s. A rest period of 15–20 min is recommended for bread varieties characterized by an open, uneven crumb cell structure, such as French-style breads.

Final molding The function of the final molder is simply to shape the dough piece as required for the bread variety being produced (see Figure 28.2). The molder should be adjusted to achieve the desired shape with a minimum amount of pressure and stress on the dough.

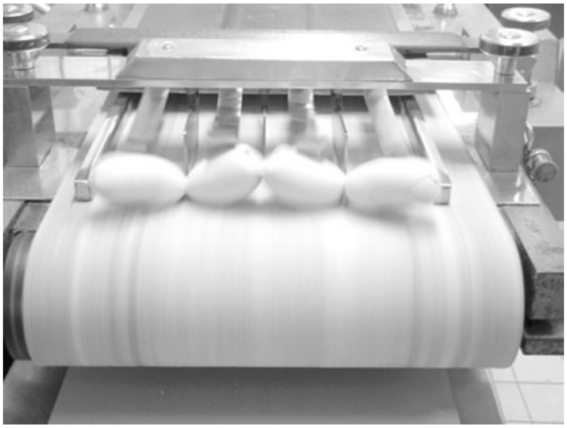

Figure 28.2 Final molder—four-piece. Courtesy of Campden BRI.

Figure 28.3 Examples of typical bread varieties found in Europe. Courtesy of Campden BRI.

Excess pressure during molding may results in damage to the gas bubble structures in the dough, as discussed previously (see streaking).

Final proof The final proof time can be adjusted over wide limits by varying yeast levels and final proof temperatures. In practice, proof temperatures of 35–43 °C and a relative humidity of 80–85% are commonly used. These humidity levels ensure that the dough does not lose moisture and form a skin on the surface that will produce a dull surface appearance.

Common bread faults and techniques for measuring bread quality

From the craft bakers who produce for the community through to the plant bakeries who engage in mass production, all bakery enterprises have their place in the baking industry. There is a wide range of processing methods used, some of which have been discussed earlier. Examples include sourdough, overnight sponges, bulk fermentation, and mechanically developed dough to name but a few.

The type of bread usually associated with the CBP would be the square sandwich loaf. However, plant bakeries do sometimes use other methods of production to produce the variations that the marketplace now demands. For the purposes of this chapter, plant production will be associated with mass-produced breads and automated processing. Craft breads would usually be associated with crusty, oven-bottom breads that include the majority of hands-on production, such as bloomers, coburgs, and baguettes.

Each type of bread possesses a number of characteristic features that are associated with quality (Figure 28.3). Sandwich bread should have an even, close crumb structure with a thin soft crust, whereas baguette production needs to deliver a random and open crumb structure and an "egg shell" crisp crust. Any deviation from these characteristics will be judged as poor quality.

Bread faults

Loaf quality is not the exclusive responsibility of the baker; it is a team effort. To achieve the desired product quality, the baker relies not only on the quality control and technical expertise of his ingredient suppliers and the engineering skills of machinery manufacturers, but also on wheat breeding and fundamental research.

Faults still occur, however, and it is important to identify the source of the problem as quickly as possible to avoid problems further along the supply chain. Bread faults can be divided into two broad categories: external (those that affect the external quality of bread) and internal (those that affect the bread crumb properties). External bread faults are those visible on the crust such as blisters, cracks, or sidewall collapse. Internal faults are all those associated with the crumb structure, where one needs to slice the bread to discover the fault.

External quality factors

The British 800 g white pan loaf is a useful example for showing the benefits of quality control. It accounts for the sales of almost 50% of all UK bread: about 5 million 800 g white loaves are sold daily. Not all of the 800 g white loaves are made to the same specifications. The differences shown in Figure 28.4 can be linked to the choice of ingredients, the recipe balance, and the technical ability of the bakeries involved.

Loaf volume Loaf volume is a good indication of the gas retention properties of the dough. It is an indicator of how good the flour protein is and how efficiently the baker has developed the gluten and balanced the recipe and processing requirements.

Low loaf volume can be due to either gas production or gas retention problems. Gas production is linked to yeast activity. As yeast is a living organism, it requires food and warmth to multiply and to produce carbon dioxide, which is required to expand the dough piece. There are ingredients that will retard or kill yeast activity, such as preservatives, salt, and high levels of sugar. Insufficient damaged starch within the flour (reducing the availability of fermentable sugars) will also retard yeast activity. Yeast can also exhibit reduced activity if it has been stored incorrectly.

Figure 28.4 Examples of U.K. 800 g sandwich bread. Courtesy of Campden BRI.

The gas retention properties of the dough are linked to the ability of the gluten structure to retain the carbon dioxide produced by the yeast. There are several factors that adversely affect the gas-holding properties of gluten. These include (i) low protein levels in the flour, (ii) poor dough development, (iii) lack of oxidation, and (iv) cold or tight (incorrect consistency or rheology) doughs.

Low volume can also be linked to cold final proof conditions or a short final proof. Underproved bread can be identified by "cracking," which may appear on the surface of pan breads or on the lower third of oven-bottom breads or rolls (see Figure 28.5).

Excessive loaf volume is also a quality issue that causes problems during the packaging and transportation stages of production, as well as sidewall collapse. Excessive volume can be linked to:

- the protein level in the flour being too high;
- excessive yeast or an imbalance of yeast, salt, and improver;
- high dough temperature;
- high final proof temperature;
- excessive final proof time, possibly due to delays in processing;
- excess dough scaling weight;
- small baking tins, which will give the appearance of excessive volume; and
- low baking temperature, which will cause the yeast to continue producing carbon dioxide for longer than required before being killed.

A combination of any of the above will compound the problem.

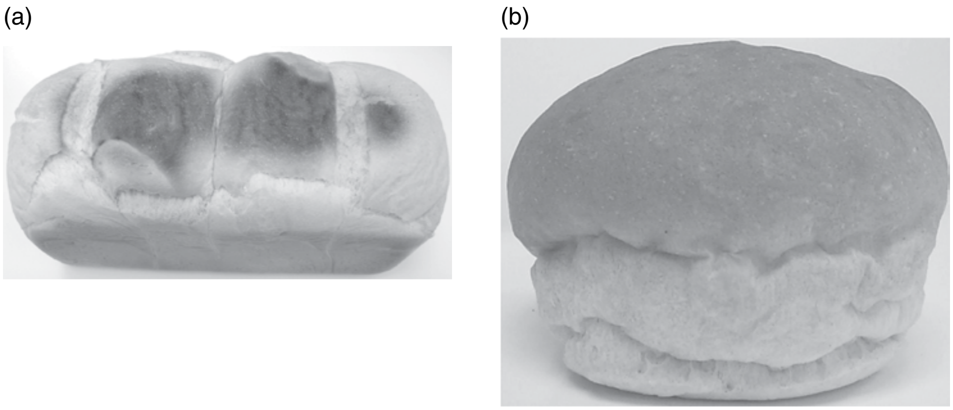

Figure 28.5 "Cracking" due to underproof. Courtesy of Campden BRI.

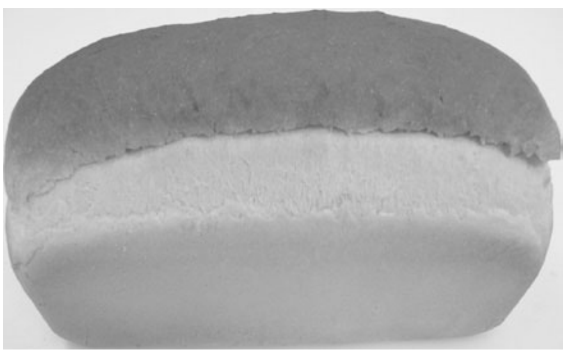

Figure 28.6 An example of a "flying-top." Courtesy of Campden BRI.

Oven-spring Another quality factor related to bread is oven-spring. It is a measure of the rise of the bread in the oven during baking. This can be measured simply by measuring the height of the bread after baking; assuming that the bread has been proved to a standard height, the difference is the oven-spring. Oven-spring is a good quality attribute when it is controlled, but uncontrolled oven-spring has a detrimental effect on finished bread quality. Excessive oven-spring can lead to "flying tops," where the top crust will detach itself from the main body of the loaf (Figure 28.6).

Surface blisters Thin-walled blisters on the surface of the baked bread indicate dough with poor gas retention properties. The blisters may not be visible until after baking, but in extreme cases the blisters will be visible at the end of the final proof. This is sometime referred to as "fat failure" and relates to the type and level of fat being used, especially in no-time doughs, where the property of the fat is a key issue. The fat helps to stabilize the bubbles within the dough; the critical time for this is at the end of final proof, during the transfer to the oven and at the beginning of the baking stage, when the bubbles are expanding at their fastest. At this stage the crystalline fraction of the fat is thought to align at the surface of the air bubbles and impart stability to the expanding bubbles. If all the fat has melted by the end of final proof, this stabilizing influence is lost. For this functionality, a fat with a slip point in the temperature range 38–45 °C is used, allowing a fraction of the fat to remain solid in the dough at the end of final proof (which is carried out at between 38 and 43 °C).

The level of fat addition will change depending on the flour characteristics; however, a level of 1% for white bread and up to 4% for whole-meal bread is not uncommon. In brown, whole-meal, germ, and multigrain breads, the fat levels are increased because the non-functional parts of the flour, such as the bran, will cause greater bubble instability in the dough. In addition to blisters there may also be reduced loaf volume and possibly no oven-spring, and the internal crumb structure may show some compact areas that appear to be firm to the touch.

Cutting After the final proof, some styles of bread are cut on the surface. This is sometimes seen as part of the identification of the product, the UK bloomer bread (a hearth bread type) being a typical example of this practice. However, this is not the only reason the dough surface is cut before baking.

- Cutting increases the surface area, which allows for a greater heat transfer into the dough. When producing oven-bottom breads cutting is very important, as there is no tin to hold the shape, and a quick heat transfer is essential to reduce the risk of flowing. Examples of this include Coburgs and bloomers.
- Cutting releases any tension in the dough and creates regions of "weakness" to facilitate dough expansion when it is put into the oven. The region where the cut is made allows a degree of control over the position of the oven-spring in the loaf.
- It is recognized that flavor is more intense in the crust. Cutting of the dough helps to increase the crust area, and this has a beneficial impact on the finished taste and crustiness of the bread. Cutting is not easy and is recognized as a great skill. The difference between a product that has been cut well and one that has not is clearly demonstrated in Figure 28.7.

Crust and crumb color The crust color is highly dependent on the time and temperature of baking. The components of the ingredients used in the formulation are also important. Flour plays an important role in the perceived color of both the crumb and crust of a loaf. The grade color of the flour will influence the crumb color of the bread. Grade color is dependent on the extraction rate and the amount of chemical bleaching given to the flour (this is no longer permitted in Europe). The use of soy flour can also affect crumb color as it contains the enzyme lipoxygenase, which reacts with the carotenoid pigments in the flour to produce a bleaching effect. The amount of damaged starch in the flour plays an important role in the extent of color development in the bread crust. If flour contains low amounts of damaged starch, there may only be sufficient sugars released by the action of α-amylase for yeast fermentation and little or no sugar left for the Maillard reaction to produce crust color during baking. This scenario would be more likely in bulk-fermented doughs and in doughs that have undergone excessive proof than in no-time doughs. On the other hand, if there are high levels of damaged starch, there will be excessive levels of sugars released, which will cause high coloring of the crust. Other ingredients that can affect crust color are the inclusion of milk powder or sugar in the recipe. High α-amylase levels (for example, low Hagberg falling number) in the dough will also break down the damaged starch, resulting in high residual sugar levels and high crust color.

(a) (b)

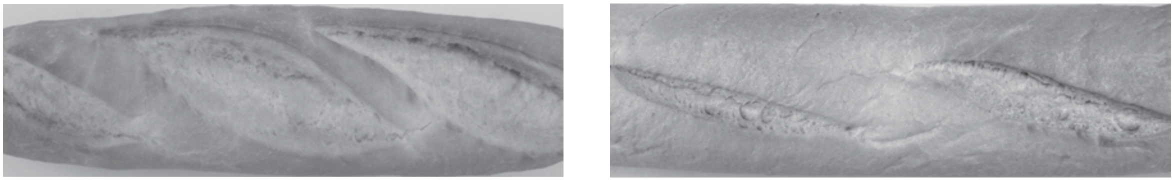

Figure 28.7 Cuts on the surface of French baguettes. (a) Good example; (b) poor example. Courtesy of Campden BRI.

Internal quality factors

The bubble structure that is generated in the dough during the mixing stage is dependent on the style of bread that is being produced. Baguettes, crusty rolls, and ciabatta all require an open irregular crumb, whereas sandwich bread requires a close even crumb structure. The crumb structure obtained will be dependent on the type of mixer used, the recipe formulation, atmospheric conditions at the end of mixing, bulk fermentation time, intermediate proof time, and final molding. It must always be borne in mind that the bubble structure at the end of mixing begins to expand shortly after it leaves the mixer, and all subsequent processing stages are designed to preserve and reorient the bubbles.

Open random structure This type of crumb structure may be required if producing ciabatta, but even then the amount of openness must be controlled so as not to cause weakness within the crumb (Collins 1983). Generally speaking, in all processes, an open crumb structure is an indication that too much gas has been produced during the final stages of processing. This can come from:

- an imbalance in the recipe formulation between the yeast and the salt, sugars, or preservatives (which will affect the amount of carbon dioxide produced by the yeast);
- incorrect vacuum level being pulled when using CBP or finishing the mixing at the wrong atmospheric pressure;
- too high a dough temperature (encouraging the yeast to work quickly); or
- delay after mixing and before final molding (with no-time dough, the period of time between the scaling and final molding stage should be no longer than 10 min, and usual times are around 4–6 min).

Cell wall thickness As the dough is processed after mixing, the aim is to maintain the bubble structure that has been developed, but the subsequent processing can damage these bubbles. The damaged bubbles will coalesce and produce areas in the crumb that look grey and dull and are firm to the touch. Small shallow air cells with thin cell walls reflect the light more efficiently, thus producing a whiter crumb; as the cell walls thicken, for example due to insufficient oxidation/development or damage to the bubbles, the color of the crumb becomes grey. When the bubbles burst, they merge into one larger bubble with thicker cell walls. The thickness of the wall influences both visual and eating qualities:

- thicker cell walls give a grey looking crumb;
- thick cell walls give a firm feel to the crumb, thus influencing perceived shelf-life;
- thin cell walls give better reflection of light and thus a whiter looking crumb.

Damage to the bubbles can be traced back to the final molding, where the dough is sheeted, rolled, and elongated either to be cut into four pieces, as in sandwich bread, or a single piece, as for the production of farmhouse bread or bloomers. Figure 28.8 shows examples of the four-piece and single-piece molding.

Excess pressure during processing will burst the bubbles. For example, having the rollers set too closely may produce grey horizontal areas running along the base of the slice. Having the guide bars set too closely will give vertical grey areas in the crumb, but these will only be visible in the end slices of the loaf.

Holes There are many types of hole that appear in the crumb, some due to the dough not being able to adhere together after curling, and others that appear due to weaknesses within the dough due to ingredients or processing.

Holes along the molding lines can be associated with (i) inadequate pressure being applied by the pressure board, (ii) dry surface due to skinning, (iii) excessive divider oil, or (iv) excessive dusting flour.

A "handbag fault" is a hole at the top of the loaf, 2–3 mm directly under the crust, that is not a blister. It appears as though the crumb has fallen away; although the surface of the

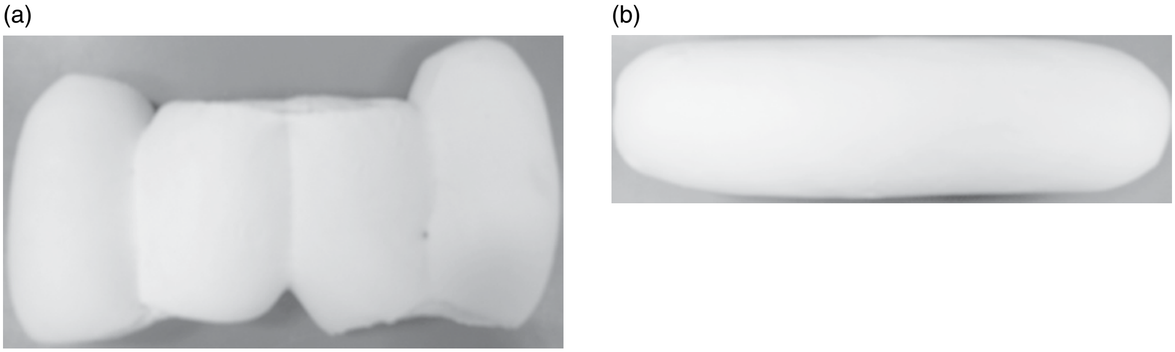

Figure 28.8 Examples of four-piece (left) and single-piece molding (right). Courtesy of Campden BRI.

hole is usually smooth, the position is always the same. This fault can be linked to excessive levels of fungal α-amylase or the addition of malt flour to the recipe. The problem may appear worse if the dough has skinned or if it is handled heavily during the transfer from the prover to the oven.

Holes in the bottom third of the loaf can be a regular occurrence in sandwich breads. They can run the length of the bread, appearing as a triangular void. Usually this type of hole is related to heat transfer during baking being too quick, which can be linked to worn bread pans. As the pans are transferred around the plant, the first areas to be worn are the bases, which means that the heat can transfer into the dough too quickly. Therefore, rather than the dough expanding gradually, the dough breaks and holes are formed. The problem can be made worse by:

- hot tins – the loaf may also show dark brown scorch marks on the side; in extreme cases these scorch marks can be white, when the yeast is killed as soon as it touches the pan, and the "dead" area is pushed away from the tin as the dough expands;
- bread pans not being greased or the insides of the pan being rough, acting like sandpaper and resisting the dough as it tries to expand up the bread tin;
- tight dough;
- excessive molding at the sheeting stage of the final molder;
- low humidity in the final prover, which dries the surface of the dough and restricts its growth before baking.

Measurement of bread quality

The quality criteria of all types of bread need to be established to determine whether they are acceptable to the consumer. The more commonly used characteristics related to bread quality are loaf volume, crumb color, and crumb quality. These measurements are routinely combined with texture measurements using texture analyzers.

Loaf volume measurements The volume of an individual loaf is typically assessed by a seed displacement method in which the product displaces a volume of seed equivalent to its own volume. The method uses a container of known volume that is calibrated by rape or pearl barley seeds, employing a dummy loaf of known volume. For a bake trial it is recommended that an appropriate number of loaves be tested and limits set for the weight of the seed that is collected for each replication.

Other methods of measuring loaf volume include the use of image analysis and methods employing ultrasound and laser light. Image analysis allows the volume of a sliced loaf to be determined by performing measurements on the cross-sectional areas of a number of slices taken from selected places along the length of the loaf and combining these measurements with the known length of the product (Cauvain 1998). More recent developments use ultrasound (Girhammar 2002) and laser sensors that move in a semicircle as a loaf rotates on a skewer passed centrally along the length of the loaf. This measurement is rapid compared with the seed displacement method, taking less than a minute to perform, and is less operator dependent.

Crumb color measurements Instrument-based measurement of the color of bread can be made using colorimeters that are designed to characterize the color of a surface by three parameters in a number of color spaces. This tristimulus method uses complex mathematical transforms to generate values in three spectral ranges, X, Y, and Z. The Y value can be taken as a measure of bread crumb whiteness. Typically the loaf is cut in half, the measuring head of the colorimeter is placed against the exposed crumb, and measurements are obtained in triplicate.

Crumb quality The judgment of crumb quality at the point of bread manufacture is typically performed subjectively by the baker who takes into account the number, size, and distribution of the bubbles and the thickness of the walls between the cells and decides whether the quality is acceptable or not. However, recent developments in the techniques of image analysis have lead to opportunities to measure crumb cell structure objectively and rapidly, allowing crumb quality assessment to be performed in greater detail and with better accuracy. Calibre Control International, in partnership with CCFRA Technology, Ltd., has developed a system called C-CELL. It is a dedicated system that produces high-resolution images of bread and other baked goods so that individual cell patterns can be quantified. Crumb cell analysis quantifies the cell distribution and the size and number of cells in a slice of bread.

Texture measurements Texture profile analysis is used for the objective measurement of bread texture. It is a rapid method and is particularly suitable for use in quality control. The principle of objective texture measurement can be described as the science of deforming objects and monitoring their response. There are numerous texture analyzers suitable for measuring the texture of bread and bread products. Typically, an instrument will consist of a flat platform and a probe, usually positioned above the platform attached to a moveable arm. The arm can be positioned precisely and moved up and down at a controlled speed.

A sample, which could consist of a circular disc cut out of a slice of bread or a whole slice of bread, is placed on the platform and compressed to a specific distance using a suitable probe. The test produces a force–time graph that represents the magnitude of the resistance of the sample to deformation. The sample may be either compressed once or compressed twice by moving the probe up and down twice in rapid succession. A typical graph of a texture profile analysis, which is characterized by two compressions, is shown in Figure 28.9. The graph consists of two peaks, each corresponding to one of the successive compressions. Typically the second peak is a little smaller than the first as a result of damage to the bread crumb structure by the first compression, and that allows the crumb structure to be compressed more easily by the second compression. There are a number of textural parameters that can be obtained from the force–time graph. The parameters and their significance are covered in detail elsewhere (for example, Bourne 1990; Cauvain 1991), so only a basic explanation is offered here. The most relevant feature for determining quality is the firmness of the bread crumb, and this is obtained from the maximum force ($F1$) of the first force peak of the first compression. Another property of interest is how

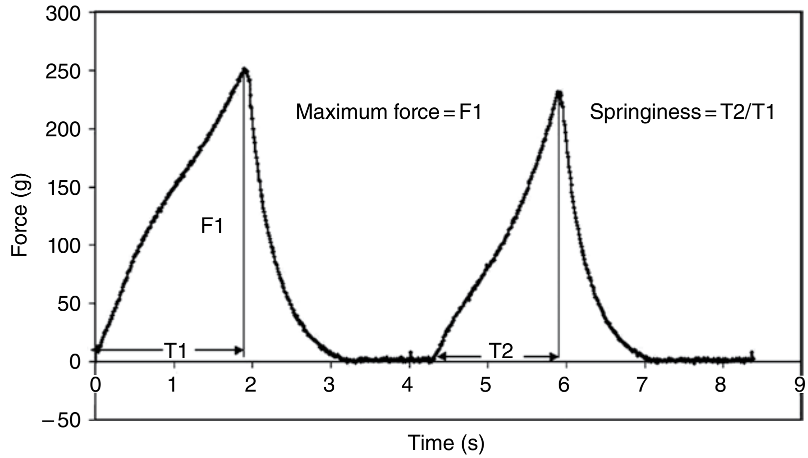

Figure 28.9 An example of the graph obtained from a texture profile analysis test.

much the bread crumb recovers after it has been compressed, that is, the springiness, which can be obtained by finding the ratio ($T2/T1$) of the time taken to reach the second peak ($T2$) to the time taken to reach the first peak ($T1$). The areas under the first and second peak also provide useful information about the ability of the crumb to withstand compression. This ratio of the integrated area of the second peak divided by the area of the first peak is called the cohesiveness of the crumb.

The properties of the crust, in particular, the crispness of the crust, also influence the eating quality of bread. The strength of the crust and hence its crispness can be evaluated using penetrometry, again using a texture analyzer. This procedure can be carried out on the whole bread or baguette, and the force required for a cylinder to penetrate through the crust is recorded. The maximum force recorded relates to the thickness of the crust, a thicker crust producing a higher peak force. The highest peak height would be expected of freshly baked bread, with moisture changes after baking making the crust softer and leathery if the product is packed in an environment where it cannot lose moisture.

Factors influencing bread staling and the use of additives to improve perceived freshness

The eating quality of bread begins to change soon after baking, the quality usually deteriorating with time. This has been discovered from numerous studies involving both instrumental texture testing and sensory testing of stored bread (Setser 1996; Zobel and Kulp 1996). With time, bread becomes firmer, and bread was judged to be stale by a sensory panel as the firmness increased. There is, therefore, a correlation between the firmness of the bread and the sensory perception of its freshness. It is therefore important to keep the bread soft for it to be perceived as fresh by the consumer for longer.

The deterioration processes affect both the crumb and the crust, but in different ways. There are two main changes that are thought to be responsible for the loss in eating quality: (1) loss of moisture from the loaf and (2) the migration of moisture from the crumb to the crust. The bread also increases in firmness with time, and this is thought to be largely due to the changes in the degree of crystallinity in the starch fraction. There are also other changes such as the loss of aroma and flavor that, combined with other changes, make the bread unacceptable to the consumer. Bread staling is a wasteful process. It is therefore not unsurprising that there is considerable interest in the bread industry in finding ways to slow down the rates of the various firming processes, so that the bread can be perceived as fresh for longer.

Craft breads are often eaten soon after purchase, but sandwich bread would be expected to last 3–5 days. However, consumer pressure for bread with an ever-longer shelf-life has seen products that can stay soft and mold-free for up to 12 days. In this section, the influence of factors such as loaf specific volume and temperature on the firming properties of bread is examined, and the ingredients and methods available to the technologist to extend the shelf-life of bread are reviewed.

The effect of loaf specific volume on bread staling

The quantitative relationship between loaf specific volume and the rate of staling, as measured by changes in crumb firmness, has been investigated in great detail, covering a range of flour properties, a number of additives, and baking and storage conditions (Axford and others 1968; Elton 1969). The results showed that loaf specific volume was a major factor influencing both the rate and degree of staling, both of which decreased in a linear manner, over the range studied, as loaf volume increased.

The general understanding is that any factor that lowers the specific loaf volume of bread increases the staling rate. The converse is also true – any factor that improves the specific volume helps to reduce the rate of staling. The influence of the effects of loaf volume is important. When assessing the effectiveness of a particular additive as an antistaling agent, it is important to demonstrate whether any beneficial effect is due to an incidental increase in loaf specific volume (due to the additive) or to a specific effect independent of the loaf volume. The beneficial effect of many so-called antistaling agents and processing methods can be explained by their incidental effect in improving loaf volume. However, additives that have been identified as independent of this factor include the enzyme maltogenic α-amylase, which has been demonstrated to possess strong antistaling properties, and emulsifiers such as glycerol monostearate.

The practical implications of the influence of loaf specific volume on bread staling can be utilized by the baker in various ways but has obvious limitations. The British public has a distinct preference for the denser more traditional product, and an increase in specific loaf volume may produce an unacceptable product.

The bread making process itself can also have an influence on the rate of staling. For example, the use of the CBP usually leads to an increase in loaf specific volume (other things being equal) and hence a reduction in the rate and extent of staling. It has been demonstrated that the reduction in the staling rate of bread made by the CBP is an inherent feature of the process and not just a reflection of increased specific volume. The conclusion was reached from the observations that the rate and extent of staling of CBP bread varied less with changes in specific volume than that in bread produced by the bulk fermentation process (BFP). The underlying reason for the differences in behavior could be that the limiting firmness of the CBP bread was lower than that of the BFP bread at a given specific volume. Using differential scanning calorimetry, it was confirmed that the limiting endothermic peak values were significantly larger for BFP bread than for CBP bread.

The effect of temperature on bread staling

The rate of staling of bread during storage is highly dependent on the temperature of storage postbaking. The rate of bread crumb firming is fastest at temperatures close to 4 °C, decreases at temperatures below and above 4 °C (Kent and

Evers 1994; Colwell and others 1969), and falls to virtually zero when the bread is frozen. It was shown that for any given bread stored at different temperatures, over the range 21–32 °C, the value of the limiting crumb modulus remained constant. The value of the rate constant was also shown to decrease with increasing storage temperature over the same range. This meant that no matter what the storage temperature was above the freezing point of bread, the bread tended to reach the same limiting firmness, though the rate decreases as the temperature increases. The fact that the staling rate constant has a negative temperature coefficient strongly indicates that a physical process such as crystallization is the major factor involved in increasing the crumb firmness. However, it was shown that the increase in crumb firmness of bread stored at 43 °C was greater than would be predicted on the basis of starch crystallization. This raises the possibility that other mechanisms are also responsible for additional increases in firmness at high storage temperatures (Willhoft 1973).

It is well known that if stale bread is heated to a center crumb temperature that is close to the temperature at the end of baking, the crumb firmness returns to its original value and staling proceeds again at the normal rate (Zobel and Kulp 1996). If the temperature attained is lower during reheating, then the original firmness may be obtained, but the loaf firms more quickly thereafter. Note that reheating bread using a conventional oven results in considerable moisture loss, and the loaf may become unacceptably dry for eating.

The effect of additives

Ingredients such as fat and emulsifiers, generally regarded as antistaling agents, often produce an increase in loaf volume, and this would then be expected to result in lower firmness initially and throughout its shelf-life. However, increasing loaf specific volume is not always desirable for commercial reasons. It is therefore important to evaluate whether an ingredient can produce a decreased rate of staling independent of its effect on volume. Both emulsifiers and enzymes have been claimed to act as antistaling agents in bread. However, at this stage a distinction must be made between ingredients that actually slow that rate of firming and those that simply soften the bread crumb without affecting the rate at which a loaf firms with storage. Such materials produce a loaf with low initial firmness, and the firmness stays low throughout the shelf-life of the loaf.

Emulsifiers such as distilled monoglycerides, diacetyl tartaric acid esters of mono- and diglycerides, and sodium steroyl-2-lactylate are likely to act as antistaling agents through one or more of three mechanisms: (1) they can improve crumb softness by increasing loaf volume; (2) they can interfere with the rate and/or extent of starch crystallization; (3) the amylose–emulsifier complex formation can slow down the crystallization of the amylopectin, thus reducing the initial and final firmness of the loaf. The distilled monoglycerides, particularly those with saturated fatty acids with chain lengths in the range C_{16} to C_{18}, are known to act as crumb softeners through the third mechanism. Many studies have shown that the amylose fraction of the starch is fully retrograded by the time the loaf is cooled to ambient temperature and that increasing crumb firmness is due to the slower process of amylopectin crystallization (Russell 1983; Krog and others 1989).

Enzymes

Enzymes have a long history of being used as antistaling agents. Claims of antistaling effects have been made for all the α-amylases, including the bacterial, fungal, maltogenic, and even the cereal types, but not for cereal β-amylases. Similar claims have been made for hemicellulases and lipases. For several of these enzymes, there are conflicting reports about whether they possess true antistaling properties. It is likely that some of them simply soften the bread by increasing loaf volume. Such effects may be useful in commercial practice to give an improvement in the perceived freshness to the consumer, provided there is a minimum firmness and resilience in the fresh bread for handling and slicing.

Amylases hydrolyze starch polymers when the starch granules are hydrated and swollen, as they are after gelatinization or damage by milling. All types of α-amylases act on starch as it swells in water at about 65 °C.

Fungal amylase is an endo-acting enzyme that attacks starch chains randomly, producing large dextrins and thinning starch viscosity to improve loaf volume. It is rapidly destroyed at 70–75 °C and has no significant antifirming effect other than that caused by increased loaf volume.

Cereal amylase is also endo-acting and has a similar action to that of fungal amylase, causing damage to starch granules and leading to dough softening. It has greater thermostability, being destroyed at 80–85 °C. If present at too high a level it can lead to a sticky crumb lacking in resilience. There are some reports of an antistaling effect, but this may be confused with the softening of the crumb.

Maltogenic bacterial amylases act as exo-enzymes (working along the chain of the starch molecules) and produce small sugar molecules such as maltose and maltotriose. This group of amylases has a large antistaling effect and is reported to reduce the rate of starch crystallization (Si 1998). These amylases seem to maintain crumb resilience, which can be a problem with excessive use of crumb softening emulsifiers, and are destroyed in baking by 85 °C and therefore would not be expected to cause problems with crumb stickiness.

The hemicelluloses of wheat consist of a mixture of polysaccharides, arabinoxylans, arabinogalactans, and β-glucans. These materials are found in the cell wall material of wheat endosperm and are present at high levels in the bran tissues. White flour may contain 2–3% of this material, of which the soluble portion (about one-third) is known as pentosans and the remaining portion is water insoluble aggregates. Of particular interest is the reported powerful effect they have on water binding and gluten development in the dough. Endo-acting hydrolytic *hemicellulases* can degrade the aggregates by splitting the polysaccharide chains, so that the insoluble material becomes soluble, and their water-binding capacity is reduced. The result, similar to that produced by α-amylase, is a softer dough that can expand more in the oven and produce a larger loaf volume. However, excessive enzyme activity can produce dough stickiness. A secondary benefit of the enzyme action on the insoluble aggregates is an improvement in the performance of the flour proteins. The conversion of the insoluble fraction into smaller molecular size allows the gluten to have better gas-holding and extensional properties during oven-spring, resulting in improved loaf volume. The best effects are seen with endoxylanases, and pure forms of some enzymes are commercially available.

The 1,3-specific *lipases* cleave the bond between the fatty acid esters and glycerol, producing a mixture of fatty acids and monoglycerides. It is claimed that the monoglycerides produced may be used to replace added monoglycerides (Christiansen and others 2003). This would depend largely on the triglyceride being attacked. Saturated fatty acids with chain lengths of 14–18 carbon atoms are the most effective antistaling monoglycerides (Russell 1983). They function by forming complexes with amylose molecules, and this helps to reduce the rate at which amylopectin molecules retrograde and increase the firmness of the bread crumb. In commercial practice, monoglycerides are added at concentrations of 0.5–1.0% flour weight. It has not been established whether added lipase can produce the amount of monoglycerides required to obtain the necessary antifirming properties in bread.

The benefits of an antistaling agent to the loaf can be classed into two main categories:

1. A reduction in the crumb limiting firmness would be of commercial importance, as the actual rate of crumb firming would be reduced. A softer loaf is perceived to be fresher by the consumer compared with a firmer loaf. This would not necessarily have an effect on the rate of staling.
2. The more fundamental action of the additive on the actual rate of crystallization of the

starch molecules would reduce the rate of staling. The addition of α-amylase to reduce the rate of staling falls into this second category, as does the effect of storage temperature.

When evaluating potential ingredients as antistaling additives, an assessment of the beneficial effect resulting from an incidental increase in loaf specific volume should be made. It must also be noted that the baking test itself has inherent variability and that it would be necessary to perform several replicate experiments to demonstrate true antistaling properties. Analytical techniques such as differential scanning calorimetry can be used as a rapid testing method, however, and this method has the advantage of being independent of loaf volume. The effect of loaf specific volume can be removed by the use of techniques such as differential scanning calorimetry and differential thermal analysis to evaluate the effectiveness of antistaling additives on the rate and extent of crystallization of starch in bread.

Recent developments and future prospects

The role of ingredients and methods of dough mixing have a large impact on bread quality. New developments employing combinations of pressure and vacuum can be used to create a whole range of bread crumb features that encompass a variety of different bread types. Using the same ingredients, a number of different bread types can be produced by changing the dough mixing methods. However, the critical feature to achieving the desired quality of the final product is actual control of the mixing process so that dough development is complete.

Various techniques to control the quality of bread dough have been explored. Rheological properties help to determine dough quality during mechanical handling and to predict bread performance (Stojceska and Butler 2012). Correlation between the rheological properties and the baking performance is proposed to depend on the characteristics of flour and its protein content as well as the type of rheological test applied. Some specific instruments have been developed for the characterization of large-deformation properties of dough such as the Farinograph, the Mixograph, the Extensograph, and the dough inflation system. In particular, the Farinograph and the Mixograph measure the torque profile generated during mixing. Large-deformation rheological tests showed a better discrimination of baking performance than fundamental rheological methods (Dobraszczyk and Salmanowicz 2008). It was demonstrated that three large deformation rheological tests – the Kieffer dough extensibility system, the D/R dough inflation system and the Mixograph test – produced a positive correlation with the bread volume (Dobraszczyk 1997, 1999).

However, all the physical measurements that describe the rheological properties of dough cannot fully predict its baking quality. Why this should be so is not clear, but it may be a consequence of what the tests actually measure. Rheology-based methods measure protein–protein interactions, which create a three-dimensional network of gluten. Hence, it is the strength of these interactions that is being measured. A study reported that the gliadin:glutenin ratio of flour has a correlation with the rheological properties of dough and bread quality (Barak 2013). The glutenin subunits can be quantified by using sodium dodecyl sulphate polyacrylamide gel electrophoresis (SDS-PAGE) and allele-specific polymerase chain reaction (PCR) (Ram and others 2011). The near-infrared (NIR) technique has also been examined for use in obtaining more information about the chemical changes that take place in the dough during mixing (Alava and others 2001). NIR energy is absorbed by the OH groups in water and by peptide bonds between amino acids in proteins at specific wavelengths. There is a correlation between the molecular analysis results produced by NIR reflectance spectroscopy and the dough rheological properties determined by alveograph (Arazuri and others 2012).

There is considerable interest in understanding what becomes of the bubbles that are in the dough before proof and after baking. Do all bubbles survive during proof and the baking process and appear as holes in the bread crumb? One of the problems experienced with studies involving dough is the fragility of the dough as it undergoes proof. The challenge has been to study bubble development during proving without damaging the cell structure by using a non-invasive technique. Campden and Chorleywood Food Research Association (CCFRA) have used a medical X-ray CT scanner to obtain images of dough during the proving stages, and some answers are now emerging about the behaviour of bubbles (Joppen 2003; Whitworth and Alava 1999). The connectivity of cell structure in bread was also successfully visualized in three dimensions through X-ray tomography images (Wang and others 2011). Indeed, image analysis of dough using magnetic resonance imaging (MRI) has also become popular due to its non-invasive nature and relatively high spatial resolution. The acquired images can be used to analyze dough pore distribution, dough volume, and bread crust thickness (Bajd and Serša 2011). Use of advanced image analysis techniques is continuing to improve our understanding of the influences of factors such as wheat varieties, recipe formulations, and mixing conditions.

The consumer's demand for healthier products drives the innovations in producing healthier bakery products. Bread has an advantage as it can be used as a medium to carry some functional ingredients. Modifications of bread ingredients are made to enhance the nutritional values of bread. Novel flour and traditional grains have been substituted into the bread formula, such as amaranth (Sanz-Penella and others 2013) and oat, spelt, rye, and buckwheat (Angioloni and Collar, 2011a) as a multigrain blend, to improve the nutritive values of bread. Also, there is a growing trend of fortifying bread with phytochemical-based ingredients. These ingredients enhance the nutritional quality of bread (such as protein, mineral, antioxidant, dietary fibre fraction, and resistant starch) and lower the amount of digestible starch in bread.

Developing bakery ingredients for people with special dietary needs are also of increasing concern. Barley and oat-based bread containing soluble dietary fiber (β-glucan) helps to reduce the total cholesterol (TC) but not change the blood glucose level (Tiwari and Cummins, 2012). Bread supplemented with omega-3 fatty acid has been produced commercially throughout the world, with a claim that it increases the amount of high density lipoproteins (HDL) and reduces the level of triglycerides (Hayta and Ozugur 2012). A type of reduced-caloric density, high-fibre bread was created by adding hydrocolloids and prebiotic oligosaccharides (Angioloni and Collar, 2011b). This product offers a higher amount of resistant starch and a lower amount of digestible starch, which is connected to the lowering of the glycemic index tested *in vitro*.

A longer shelf-life of bread is highly desired by the modern bakery industry to meet the consumer's demand of convenient bakery products. Frozen dough technology can reduce the problem of having bread staled by making fresh bread available at anytime of the day. Frozen dough can be used to increase the shelf-life of bread up to 12 months. A variety of processes to make frozen dough can be applied, including fully baked frozen bread (FBF), partially baked frozen bread (PBF) and bread from unfermented frozen dough (UFD). Improving the quality of frozen dough is still being discussed and studied to grow the market of this product (Rosell and Gomez 2007). Incorporating the dough with hydrocolloids, emulsifiers, oxidants and cryoprotectants (Minervini and others 2011), enzymes such as glucolipase, hemicellulase and hexose oxidase (Almeida and Chang 2012) or soy proteins (Simmons and others 2012) have been reported to be able to improve the quality of frozen dough.

The shelf-life extension of bread is closely related to its packaging, which functions to minimize some reactions due to the contact of bread with water vapour and oxygen in the environment. Modified atmosphere packaging

($60\%\ CO_2$, $40\%\ N_2$) was applied to extend the shelf-life of bread with acceptable sensory quality up to 24 days at 20 °C (Fik and others 2012). Active packaging can also be applied to improve the shelf-life of bread, for example by applying ethanol emitters and oxygen absorbers (Latou 2011).

Consumers are also showing concern about the nature of the ingredients that are included in a recipe to improve the quality of bread. The enzyme lipase was shown to improve bread quality attributes (bread volume and texture) and it could be used to replace some chemical emulsifiers such as diacetyl tartaric esters of mono-glycerides (DATEM) (Moayedallaie and others 2010). Claims are that the action of the enzyme, *in situ*, generates materials that are more surface active than the substrate material. This offers an opportunity to either eliminate or reduce the use of added emulsifier and thus remove the need to declare additives on the packaging. The importance of this development is highlighted by a marked increase in the sale of organic bread products, which will continue as the range of breads produced is increased. The negative response of the consumer to products labelled as organic is being replaced by a realization that the quality parameters by which an organic product should be judged are different from those applied to bread produced with traditional ingredients.

Bread producers are also faced with the situation whereby popular dietary trends, such as the Atkins diet, are forcing the industry to rethink recipe formulations to produce acceptable alternatives. The challenge of producing such a (low carbohydrate) loaf is an interesting one, since carbohydrates play such a vital role in building the structure of bakery products.

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