Bread and Other Bakery Products 15

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15.1 Introduction

The term bakery products covers a diverse range of foods which are linked by the common thread that their recipes contain a significant proportion of wheat flour. The proteins in wheat flour have the special property that when hydrated with water and subjected to mechanical agitation they form the viscoelastic material which is commonly referred to as gluten (Cauvain, 2015). While based on wheat flour the significant formation of a gluten network is not common to all classes of baked products. Gluten formation is essential in the production of bread since the network which is formed enables the trapping of air bubbles which will later be inflated by the production of carbon dioxide gas from bakers' yeast fermentation (Cauvain, 2003a). The transition from flour, water, salt, yeast, and other functional ingredients to a baked loaf of bread is commonly described as an example of a change from a foam to a sponge. In the foam gas bubbles which have been incorporated during mixing are separated by the gluten network and are therefore discrete from one another while in the sponge the gas cells are open and interconnected. This transition gives bread its characteristic finished cellular structure (Cauvain and Young, 2006a).

The other classes of bakery products which fit the foam to sponge model are the many varieties of cakes and sponges. However, in these products gluten formation is so limited as to play little or no part in the formation of the initial foam (Cauvain and Young, 2006a) and the foam stabilizing mechanism is quite different from that in bread and relies more on the egg proteins, fats, and emulsifiers (Cauvain, 2003b). The final cakes and sponges do have a cellular structure similar in many ways to that of bread but their eating characters are very different in part because of the lack of gluten formation in the mixed batter arising from differences in recipe and processing conditions. Gluten formation in dough used to manufacture biscuits, cookies, and pastries is also limited in part because recipe water levels are low and in part because gluten development can contribute to final product quality defects (Manley, 2000). An exception for significant gluten development is the manufacture of laminated products such as puff pastry and croissant. In this case it is necessary to develop a gluten network in the base dough so that it can be successfully sheeted and a structure of alternate and discrete layers of dough and fat built up to deliver the typical flaky eating quality that characterizes such products (Cauvain and Young, 2006a).

The Stability and Shelf Life of Food. http://dx.doi.org/10.1016/B978-0-08-100435-7.00015-0

15.2 A Brief Overview of the Manufacture of Bakery Products

15.2.1 Bread

The production of bread and other fermented products accounts for the greatest volume proportion of all manufactured baked products. Breads come in a wide variety of forms (Fig. 15.1) and apparently different processes, but the underlying principles involved in their production are remarkably similar. Essentially the processes all involve the mixing of wheat flour, water, yeast, salt, and other functional ingredients in the development of a gluten structure in the dough, the preparation and shaping of individual dough pieces, their fermentation, and finally the heat-setting step called baking (Cauvain, 2001).

The different breadmaking processes vary most in the manner in which the dough ingredients are mixed and the gluten network is developed. Cauvain (2015) divided the main breadmaking processes into four main groups:

- Straight dough bulk fermentation
- Sponge and dough
- Rapid processing
- Mechanical dough development.

Each of the processes employed in the main breadmaking groups tends to yield slightly different characteristics in the final product which has implications for the shelf life and stability of the product as will be discussed below.

The first process, straight dough bulk fermentation, is considered by some to be the most traditional. Its essential features are based on the mixing of the ingredients to form a homogeneous dough followed by resting of the dough in bulk for a prescribed time (floor time), depending on flour quality, yeast level, dough temperature, and the bread

Figure 15.1 Bread varieties.

variety being produced. Dough mixing is usually carried out at low speed and little energy is imparted to the dough. Because of this approach the development of a suitable gluten network relies heavily on the enzymatic processes which take place during the fermentation period. The length of the bulk fermentation period may vary from 1 to 16 h depending on the requirements of the baker, commonly periods of 2−4 h are used.

The second group, sponge and dough, has elements similar to those for bulk fermentation but in this case only part of the ingredients (the sponge) are given any significant fermentation. This is followed by the mixing of the sponge with the remainder of the ingredients to form a homogenous dough and its immediate processing. The process is commonly used in North America. It is common to use the same type of flour in both the sponge and the dough-making stages.

The rapid processing group covers a heterogeneous collection of processes which have evolved based on different combinations of active ingredients and processing methods. A common element within this process group is the inclusion of functional ingredients to assist in dough development and the reduction of any individual fermentation period, in bulk or as divided pieces (but not including proof), to less than 1 h.

The final group, mechanical dough development, is characterized by the mixing and development of the dough in one single operation and the absence of a bulk fermentation period. The best known and most widely used of the mechanical dough development processes is the one launched in the United Kingdom in 1961, the Chorleywood Bread Process (CBP), and it is in use in many counties around the world today (Cauvain and Young, 2006b). The essential features of the CBP are the mixing and development of a dough to defined energy input in 2−5 min, the control of mixer headspace atmosphere to achieve given bread cell structures, and the addition of a bread improver (now ascorbic acid). An important aspect of the CBP that is not readily available in other breadmaking processes is the potential for direct control of the cell structure in the final bread by adjusting the pressure applied during mixing. This versatility enables a variety of bread types to be made from the same dough formulation and processing equipment (Cauvain, 1994; Cauvain and Young, 2006b).

After leaving the mixer the processing of the dough to become bread follows essentially the same pattern whichever breadmaking process is used. The main steps are the subdivision of the bulk dough into unit pieces, their shaping, expansion through fermentation in the prover (proof), baking in the oven, and cooling before consumption (Cauvain, 2001).

15.2.2 Cakes

Cake batters are a complex emulsion and foam system (Cauvain, 2003b). Minute air bubbles are trapped in the batter by the surface-active proteins in the egg, fat, a suitable emulsifier, or a combination of all three. Because high levels of water and liquid egg are used in cake recipes the resulting batter has a low viscosity and gluten formation is limited. The low viscosity of cake batters allows them to be easily deposited and there is seldom any postdepositor processing. The batter is held in pans or deposited directly onto the oven band (eg, Swiss roll) to be quickly heat-set in the oven. Some of the wide variety of cake products are illustrated in Fig. 15.2.

Figure 15.2 Cake varieties.

15.2.3 Biscuits and Cookies

The levels of water used in the mixing of biscuit dough are low by comparison with bread, partly to limit the formation of gluten and partly to reduce the amount of water that needs to be driven off during baking to ensure that the final products have the hard-eating qualities which is a key characteristic of these products. The consistency of biscuit and cookies doughs plays a very important part in the choice and operation of a particular production process. Individual pieces may be formed from the bulk dough after mixing by sheeting followed by cutting (sheet and cut), by pressing dough into a mold and then extracting it for baking (rotary molding), or by extrusion of a cylinder from which unit pieces are cut (wire cut). There is seldom any postforming processing and the pieces usually move quickly to the oven for baking. A selection of biscuit and cookie types is illustrated in Fig. 15.3.

Figure 15.3 A selection of biscuit and cookie types.

Figure 15.4 Croissant.

15.2.4 Pastry

The main forms of pastry either are based on a short dough prepared in a similar manner to biscuit dough or are laminated pastries. The former are usually shaped with some form of blocking die while the production of the latter is based on preparing dough sheets to encase layers of fat (Cauvain and Young, 2006a); with successive sheeting and folding the alternating layers of dough and fat yield a characteristic flaky structure. Puff pastry is the main example of a laminated paste and there are related products such as Danish pastry, croissant (Fig. 15.4), and crackers which are yeast-raised.

15.3 The Key "Fresh" Characteristics of Bakery Products

15.3.1 Bread, Rolls, and Buns

This group of products is characterized by having a "crust," a dry, thin layer enclosing the soft, cellular structure of the crumb. Bread crust has considerably lower moisture content than that of the crumb; typically crust moisture contents are in the range 12−17%, while for the crumb they will range from 35% to 42%, depending on bread type. The low moisture crust has a hard and brittle eating character which may be accentuated by the thickness of the crust. All fermented bread products have an open, cellular crumb structure. A fundamental requirement of bread crumb is that it should be relatively soft combined with a degree of resilience or springiness and a degree of "chewiness." An important contributor to the character of bread crumb is the nature of the cellular structure as determined by the size of the individual cells, their distribution throughout the product, and the thickness of the cell wall material. While objectives methods have been developed to evaluate such characteristics of bread crumb (Whitworth et al., 2004; Cauvain, 2013) the contribution of such features to the stability and sensory shelf life of products has yet to be evaluated.

The water activity of bread is high (around 0.95) and its mold-free shelf life (MFSL) relatively short, typically 4−10 days, depending on storage conditions and whether preservatives are used. There are other short-term changes in both the crust and the crumb of breads which affect its shelf life.

15.3.2 Cakes and Sponges

These products may be classified as intermediate moisture foods with moisture contents in the range 18−30% of the product mass. Cake products do have a thin crust but it does not usually have significantly less moisture than the crumb. The cellular structure of cakes tends to be less well defined than that of bread, though there is considerable variation. A key attribute of cakes is the relatively longer shelf life which they enjoy (often many weeks) compared with that of bread (a few days).

15.3.3 Biscuits, Crackers, and Cookies

These products are much smaller in unit size and weight than other bakery products. Their moisture contents are typically under 5% and the low moisture content coupled with the thinness of the products gives them a crisp, hard-eating character though this may be moderated with higher recipe fat levels. The low moisture content and low water activity of products in this group (typically <0.5) mean that they have long MFSLs, typically many months (Manley, 2000).

15.3.4 Pastries

Pastry products are a versatile medium which can be considered as an "edible packaging." The intimate contact between pastry and the different fillings used yields a wide range of product textures, moisture contents, and water activities. The pastry component tends to have higher moisture contents than biscuits but below that of cake. Typically fresh pastries have a firm and relatively crisp eating character when freshly baked. The shelf life of the pastry can be quite long but the migration of moisture from filling to paste (Cauvain and Young, 2008) reduces this life considerably so that typical shelf lives will range from a few days for meat-containing pastries (even when refrigerated) to a few weeks for pastries with sweet fillings.

15.4 Factors Affecting the Stability of Bread and Other Bakery Products

15.4.1 The Nature of Staling in Bakery Products

The main physical changes which take place during the storage of bakery products are summarized in Table 15.1. The relative importance of each of these changes in baked

Table 15.1 Physical Changes in Bakery Product Character During Storage

Product Character	Examples of the Nature of the Change During Storage
Crust crispness	Loss of bread crust crispness through moisture migration from the crumb.
Product crispness	Softening of biscuits through absorption of moisture from the atmosphere. Loss of pastry crispness through moisture migration from the filling.
Crust moisture	Increase in bread crust moisture because of moisture migration from the crumb.
Crumb moisture	Dehydration of unwrapped bread crumb. In fruited bread products migration of water from crumb to fruit (Marston, 1983).
Crumb firmness	Firming of bread crumb through starch retrogradation (staling) in the absence of moisture loss.
Crumbliness	Increased friability of cake crumb through staling or moisture migration in fruited products.

product character will depend on the type of product being made as shown by the few examples recorded in Table 15.1. For example, the loss of crust crispness will be less important in pan breads than in hearth breads or baguette. All of the changes that occur during storage tend to be embraced by the term staling, although loss of perceived freshness may be a more appropriate term, because for cereal scientists staling has become mostly associated with the changes that occur in the crystallinity of the wheat starch in baked products during storage.

In the oven, the wheat starch present in bread dough and cake batter undergoes the transformation known as *gelatinization.* In the unbaked starch, it is the amylopectin fraction which contains ordered regions and is embedded in the noncrystalline matrix of the amylose, the other main constituent of the lenticular wheat starch granules (Schoch, 1945). The starch granules are largely insoluble in cold water, but when heated in an aqueous medium they begin to absorb water and swell. Penetration of the warm water into the granules contributes to a loss of crystallinity in their structure, and as the temperature begins to rise, the intermolecular bonds of the starch polymers begin to break. This increases the number of hydrogen bonds available for the water present, and the viscosity of the starch−water mixture begins to increase. Further heating of the mixture results in a change from a viscous liquid to a solid, and this point is regarded as the gelatinization temperature of the starch. In bread, gelatinization occurs in the region of 60−65°C (140−149°F) while in cakes where large quantities of sugar are present in the batter, the gelatinization temperature may rise to 90°C (194°F).

On cooling, the starch polymers begin to lose their mobility and they “retrograde” and their increase in crystallinity increases. This retrogradation continues during storage and contributes to the firming that typically occurs with bread and cake crumb even when no moisture is lost from the product. Retrogradation is both time and temperature dependent as described by Cornford et al. (1964). The maximum staling rate for bread occurs at around 4°C (Cauvain and Young, 2008) and below that temperature the rate decreases.

It is generally considered that the water level in the baked product needs to be greater than 20−30% for retrogradation to occur and, as noted above, the moisture content of bread crumb readily exceeds such levels. During storage, water is redistributed throughout the loaf structure. On the macroscopic scale this involves the movement of moisture from crumb to crust while on the microscopic scale there is movement between starch and protein. There is no consensus favored view as to the direction of moisture movement with Wilhoft (1973) favoring a loss of moisture from the gluten to the starch during storage, and D'Appolonia and Morad (1981) favoring the reverse. This lack of clarity arises partly from the overlap in the glass transition temperature ranges for starch and gluten for a given moisture content, and partly from the close physical relationship of the polymers in the crumb. In bread crumb, the starch granules are attached to the continuous gluten network formed in the dough (Rao et al., 1992) and this close physical association provides a ready opportunity for moisture migration.

The glass transition temperature (Tg) is a commonly used parameter for determining the stability of bread (Slade and Levine, 1991). It is related to the transition of materials from a rubbery to a more brittle, glass-like state in which the material will exhibit more solid-like properties. As such it can be used to describe the firming of bread crumb which occurs without the loss of moisture. As noted above, in bread crumb at the molecular level both the protein and the starch polymers appear to be involved in bread crumb staling.

Bread staling is a two-stage process involving both the amylose and the amylopectin fractions of the starch. The generally accepted mechanism is that soon after leaving the oven the amylose fraction retrogrades and makes a significant contribution to the initial firming of bread so that it can be sliced commercially within the first couple of hours after leaving the oven. It has been known for some time that the longer term firming (which takes place over several days and need not involve moisture loss) is associated with the amylopectin fraction of the starch (Schoch and French, 1947). Gray and Bemiller (2003) considered that the coagulated gluten network in bread crumb after baking served as a reservoir for water which when transferred to the gelatinized starch initiates retrogradation and this view might also explain the apparently contradictory views on whether the protein or starch structure has the greatest impact on bread staling.

Reheating stale bread softens the crumb provided that all of the product is raised to a temperature of 60°C or higher according to some sources (Zobel and Kulp, 1996). Such temperatures are required to ensure that all of the recrystallizing starch is melted. After being refreshed, the subsequent rate of staling increases significantly by comparison with that which previously prevailed. This increase in the second staling rate is exacerbated by any crystals which remain unmelted on reheating. There may be some restoration of crust crispness on reheating and there will be further loss of water from the product crust region and the reestablishment on a moisture gradient in the product.

The behavior of the crumb and crust on reheating is especially important in the manufacture and use of par(t)-baked products (Cauvain, 2014). The first step in their manufacture is to deliver a product in which the internal structure is developed but without significant crust color formation. The second stage (bake off) reheats and refreshes the crumb and crisps and colors the crust. However, as noted above if the internal product temperature does not exceed at least 60°C on reheating then problems with accelerated staling can be encountered after the second bake.

Cake crumb also loses its freshness and becomes firmer during storage. As with bread this may arise even when the conditions are such as to prevent moisture loss. Two subprocesses contribute to cake staling: the loss of moisture from the crumb by diffusion to the crust, and an intrinsic firming of the cell wall material. These two subprocesses have different temperature relationships: the first has a positive and the second a negative temperature coefficient. Both crumb-firming effects are similar to those observed with bread, but the maximum firming peak with cake products lies between 15°C and 25°C.

In all baked products there is a direct relationship between the product moisture content and the perception of product freshness. The nature of this relationship is very product specific so that in some products (eg, bread and cake crumb) higher moisture contents are equated with fresher products while in others (eg, bread crust, biscuits, and pastries) lower moisture contents are equated with fresher products. Because of these important relationships knowledge of the moisture content of a baked product and in the case of a composite baked product (eg, an apple pie), the moisture content of the individual components is very important. However, it must be recognized that while the level of moisture in a baked product is very important in the perception of its quality other properties such as water activity (see below) are at least equally important in understanding and, ultimately, controlling product shelf life in the fullest sense of the term.

15.4.2 The Impact of Freezing on Bakery Products

The freezing of foods is commonly used to extend their shelf lives to many months. The effect of the initial freezing is related mainly to ice crystal formation, with slow freezing favoring larger and fast freezing, smaller ice crystals. In this context the stability of frozen foods during storage is controlled by the temperature difference between the freezer temperature and the T_g of the system. There is a positive correlation between T_g and stability at a constant freezer temperature (Levine and Slade, 1988). Freezing reduces reaction rates but at the same time freeze concentration may increase reaction rates. At typical freezer temperatures the high viscosity of the aqueous phase in a baked product becomes so high that reactions and movements of solutes are greatly inhibited below the T_g of the matrix and the water is kinetically metastable.

The realization that the glass transition temperatures of bakery products are important in relation to their storage stability leads to the conclusion that deep freezing offers a means to limit staling. For bread this is true provided that it passes as rapidly as possible through the region of maximum staling. This is considered to be around 4°C depending on the precise formulation. In frozen bread products this zone of maximum staling will be approached twice, once during cooling and again during defrosting. Once frozen, bread products are relatively stable if held at around −18°C to −20°C.

The instability of bread during cooling and frozen storage is shown by the simple observation that the crumb shrinks during the whole cooling process. Ribotta and Le Bail (2007) examined bread staling effects using differential scanning calorimetry and differential thermal analysis. They suggested that shrinkage of the matrix during freezing and storage was due to dehydration as a consequence of ice crystal formation and that a greater amount of retrograded starch increased the contraction capacity of bread crumb.

Cakes are less stable than bread in frozen storage, in part because of the high levels of sugar in the product. Typically the T_g of a baked cake can be as low as common deep-freezer temperatures (−18°C) and so moisture may readily escape from the apparently frozen matrix. Pateras (1996) discussed how the ice crystal formation in cakes during freezing could lead to a weakening of the physical structure of the cake crumb. A consequence of this weakening would be an increasingly fragile product less able to withstand handling and cutting. Faster freezing has a significant impact on reducing the fragility of cake crumb.

Many bakery products, especially cakes and pastries, are made up of different components (eg, a cream-filled cake), each of which has its own unique T_g. This means that not only the different components will freeze and thaw at different rates but they will also have different frozen storage stabilities at a given frozen storage temperature. Such differences complicate the ultimate effect on final product quality and a significant factor can be the effects of moisture migration.

15.4.3 Moisture Migration

The modeling of water migration in food systems is complex, not least because the different food matrices require different models. The two main factors are considered to be the rate of moisture diffusion and water activity equilibrium: the first is associated with mass transfer and the latter with thermodynamics (Labuza and Altunakar, 2007). Even a simple bakery product is complex with respect to modeling moisture migration. For example, a loaf of bread at the end of baking and for some period during storage comprises three distinct areas or zones: the low moisture and brown colored outer crust, an intermediate moisture inner crust which is white in color (essentially comprising layers of crumb which have been crushed against the crust once formed in the oven), and a higher moisture, open-structured crumb. Not only does each zone have a different moisture they also have distinctly different densities which will affect moisture diffusion rates. Piazza and Masi (1995) split the cross-section of a loaf into five vertical zones to study moisture migration in bread after baking and concluded that moisture migration was driven by the moisture gradient between the zones. In none of the zones used in their study was the crumb entirely free of accompanying crust but the basic model of moisture migration from crumb center to outer crust was as would be expected. Thus, while a number of studies have been carried out many of the considerations regarding moisture migration in bakery products remain empirical in nature and so practical models for moisture migration tend to focus on the macroscale rather than the microscale.

When baking is finished, the moisture content of the baked product crust is lower than that of its center. The moisture gradient which is present after baking may remain in the product during cooling and for some time during storage but moisture will move from the areas of higher moisture to those with lower water until equilibrium of moisture content is reached, provided that there is no loss from the product to its surroundings. The rate at which equilibrium is achieved depends on many factors, some of which are discussed in more detail below. In bread the softening of the crust and the accompanying firming of the crumb (in the absence of moisture loss) are the best known examples of the effects of moisture migrations. This phenomenon is most readily observed in oven-bottom or hearth breads, baguettes, and crusty rolls, where the softening of the crust detracts from the product character and leads to loss of consumer appeal as the formerly crisp eating crust assumes a "chewy" character. Pan breads, on the other hand, may actually benefit from this moisture migration phenomenon during storage since a crisp crust is largely undesirable with such products when they are sliced or eaten. In understanding the implications of moisture migration at the macroscale it is necessary to know not only the moisture contents but also the relevant component masses involved. For example Cauvain and Young (2008) calculated that if the low moisture crust on a sandwich loaf increased in thickness from 1 to 2 mm then there would be a resulting decrease in the equilibrium moisture content of the crumb of 1.2%, a figure which has significant implications not only for the initial perception of product quality (crumb firmness) but also for the subsequent staling rate of the product. Such considerations may explain why the crumb of crusty bread loses its apparent freshness more rapidly than that in pan breads. In crusty breads, the more open cell structure also increases the rate of moisture diffusion through the crumb, which also encourages crumb drying and crust softening.

Baik and Chinachoti (2000) followed changes in bread samples with and without crust and considered that moisture migration from crumb to crust (when present) would lead to greater crumb firmness and increased amylopectin retrogradation. Bhatt and Nagaraju (2009) used electrical impedance spectroscopy to follow changes in bread moisture content and found that the glass transition temperature of the crust occurred after 96 h when the product was held at room temperature for moisture contents above 17%. They validated their results with differential scanning calorimetry. Both studies emphasize the importance of moisture migration with bread products to subsequent bread staling and confirm practical observations.

Primo-Martin et al. (2010) studied the dynamics of moisture migration with respect to the character of the crust formed on rolls and suggested that products with a finer (small cell size) structure with fewer cell interconnections and a thicker crust had a significant positive effect on water kinetics and crust retention. Their study emphasizes the importance of the structural architecture of a baked product in delivering stability during storage postbaking.

Loss of perceived freshness as the result of moisture migration in cake products follows much the same lines as those for bread. However, cake products are not usually expected to have a crisp eating crust, and so changes in crust character are not a critical issue. In biscuits and pastries, the moisture contents are so low that moisture may migrate from the atmosphere into the product, rather than from product to atmosphere as with bread and cakes. This is a common mechanism by which cookies and pastries go soft or stale.

One particular moisture migration phenomenon in biscuit, cookies, and crackers (and occasionally in pastries) is that known as “checking.” This is the formation of cracks and splits without the products being subjected to external forces strong enough to fracture the product. It is most commonly seen in products with recipes that are low in fat and sugar, eg, semisweet biscuits such as the UK Rich Tea product. It has long been known that checking is the result of moisture migrating within the product after baking (Dunn and Bailey, 1928) and it is associated with physical weaknesses in the baked product which make it susceptible to the effects of mechanical shocks experienced in cooling, wrapping, and transport. The cracks are often radial in round products, although apparently more randomly distributed cracks may occur in products like crackers. Using a finite element modeling method Saleem et al. (2005) confirmed the critical role that the moisture gradient played in biscuit checking and showed that when the relative humidity (RH) of the atmosphere surrounding the biscuit is low enough (26% RH) to allow both absorption and desorption to occur that the stresses which are set up can cause the biscuit to crack. If the atmospheric RH was high enough for the biscuit to absorb moisture from the atmosphere the predicted stresses were insufficient to cause cracking. In practical terms a dilemma for the biscuit baker is whether to hold biscuits at a higher RH and risk them absorbing water and going soft or to ensure that they stay at a low RH and risk them checking.

Moisture migrates in bakery foods by the following mechanisms:

1. By direct diffusion from the component with the higher moisture content to the one with the lower moisture content;
2. By vapor phase transfer, where the moisture migrates from the component with the higher equilibrium relative humidity (ERH) to the one with the lower ERH;
3. By the formation of surface water through syneresis within a gel as a result of crystallization or aggregation of polymers.

The direct diffusion of moisture arises when two or more components are in intimate contact with one another. It may occur at the macroscopic level and is aided by factors such as capillary action, or it may occur at the molecular level (Labuza and Hyman, 1998). The rate of diffusion between the components depends to a large extent on the differences in water activity between the components; the greater the difference in water activity, the faster the rate of diffusion. The effects of gravity can increase the rate of diffusion to lower sections of the product. There is also some impact from the physical nature of the materials in contact with one another and in particular the porosity of the materials. The structures of many baked products, with their macroscopically broken cells, act like many small capillary tubes and moisture is drawn into them. If the material has a largely closed network with a dense, unaerated structure, rates of moisture migration will be low.

Moisture migration by vapor transfer is most evident with wrapped products. In this mechanism, moisture leaves a product component through surface evaporation to enter the surrounding atmosphere from where it can then be absorbed by another component. Vapor phase moisture transfer is not normally evident with unwrapped products because moisture at the surface is usually swept away by any air movement over the product. The role that product porosity may play in the transfer of moisture by vapor phase transfer in bakery products has probably been underestimated. The open cells of bread crumb are likely to play a significant part in the transfer of water vapor with migration occurring more rapidly through bread products with a more open structure (ie, larger voids) such as baguette, than would be the case in a product with a fine cell structure (ie, smaller voids) such as pan breads.

The shrinkage of gels due to crystallization or aggregation of polymers can cause loss of water from the surface of components. This problem is common with some starch gels, particularly those subjected to freezing and thawing. Surface water forms because of the breakdown of the gel, and subsequent release of the previously "bound" water, which may evaporate to be absorbed by other components by diffusion, or be lost from the product leading to drying out and shrinkage of the gel, or the moisture, may be transferred to another component. The staling of bread crumb is often quoted as an example of syneresis though more obvious examples are the breakdown of whipped cream foams and baked fillings like egg custards (Cauvain and Young, 2009a).

15.4.4 Equilibrium Relative Humidity (Water Activity) and Microbial Shelf Life

ERH and water activity (a_w) are terms used frequently in the description of bakery products as a means of explaining their potential stability. Water activity expresses the "availability" of the water in a given solution, whereas ERH applies, strictly speaking, to the atmosphere in contact with the solution. When the atmosphere and the solution are in equilibrium, the terms a_w and ERH can be used interchangeably. The relationship under a defined set of conditions of atmospheric temperature and pressure is straightforward and described by the following equations:

$$a_w = \mathrm{ERH}/100$$

$$\mathrm{ERH} = 100 \times a_w\%$$

Since ERH is based on the measurement of humidity, it is usual to express it as a percentage, while a_w has no units. The scale for a_w runs from 0 to 1, with 1 representing pure water; that for ERH runs from 0% to 100%, with 100% representing pure water.

For each bakery product, there is a unique relationship between its moisture content and its water activity. The precise relationship depends on whether the material being assessed is undergoing dehydration (eg, drying or baking) or hydration (eg, wheat flour proteins in dough mixing). The two different processes are usually described as *desorption* and *adsorption*, respectively. The relationship between product moisture content and a_w depends on the nature and composition of the ingredients and the processing that has been carried out to convert the ingredients into a baked product.

The stability of a baked product is dependent on both its moisture content and its a_w. Only in pure water are a_w and moisture content identical, ie, 1.0% and 100%, respectively. Once ingredients and their concentrations within a product are taken into account, along with their effects on the water availability, the moisture content and the water activity values can differ. However, it is true that as the moisture content of a given product increases or decreases, the water activity increases or decreases accordingly.

An important property of a_w is that it is temperature dependent with a_w decreasing as the temperature decreases; this can be a significant factor in affecting the stability of a food. Since many foods are not fully in equilibrium during storage, a_w may also change with storage time. While both glass transition and a_w are associated with food stability they are two different but complementary properties and a_w remains an important, practical, and easily measurable property to be considered in relation to food stability, especially with respect to microbial shelf life.

The concept of water activity was first used by Scott (1957) to show that a_w rather than moisture content determined the microbial safety of food. The growth of microorganisms is generally considered to be inhibited if the osmotic pressure of the medium on or in which the organism is located is sufficiently high. Therefore knowledge of a product's a_w or ERH is useful for identifying and understanding potential microbial issues. The ERHs of bakery foods cover a wide range running from 30% for biscuits up to 98% for creams and fillings. At values above 88% bacterial spoilage may occur but with many cake and bread products the main spoilage mechanisms involve mold growth. Research on the relationship between bakery product ERH and mold growth has led to the development of models for the prediction of product MFSL from a knowledge of its measured ERH and even to a computer-based system (ERH CALC™) which allows the estimation of a product ERH from its formula and the subsequent prediction of its MFSL (Cauvain and Young, 2008).

In general terms the microbial shelf life of bread is short and while the ERH of bread crumb is high enough to support bacterial growth this is not usually a problem and the spoilage is limited to mold growth, typically within less than 4–8 days depending on the storage temperature of the products. Rolls and buns which contain low levels of sugar in the recipe usually have a longer MFSL than standard bread in the United Kingdom. The presence of sugar in US bread formulations (Cauvain, 2015) partly accounts for the longer shelf life achieved with such products.

When all baked products leave the oven their surfaces are sterile and so it is microbial contamination of the surface during cooling that leads to product spoilage. This is also true of bakery products which are sliced, eg, cakes and bread, since the exposed surfaces tend to have higher ERHs than the product crust. While mold growth remains the main spoilage problem for bread there is one special condition associated with bacterial spoilage. The flour used to make all breads contains spores of the bacterium *Bacillus subtilis*, which can survive the combination of heat and time in the product center achieved in baking a loaf of bread. In the cooled product the ERH is high enough to permit the spores to grow. Spoilage by this bacterium is characterized by an initial "fruity" odor, followed by softening of the crumb and eventually the formation of strands of crumb when the loaf is pulled apart. Bakers refer to the formation of these strands as "rope" (Cauvain and Young, 2001). The levels of contamination are higher in wholemeal flour because the bacteria spores are associated with the bran layers of the wheat grain and the problem is more readily observed in wholemeal and multigrain breads than white. Acidification of the dough and the addition of suitable inhibitors in the recipe are commonly used to limit the problem (see below).

15.4.5 Rancidity

While many bakery products contain high level of fats, including dairy products, there are relatively few problems with oxidative rancidity. In part this is because the MFSL of the products is too short for the effects of oxidative rancidity to become noticeable. The main exception is for low ERH products such as biscuits which have very long shelf lives. In this group the problem is associated with the autooxidation of the lipids that are present in the formulations and involves any free radicals present (Bell, 2007). This usually occurs relatively rapidly in products with an a_w of less than 0.3. Bakery products containing nuts and oats with naturally high fat contents and free radicals can often be susceptible to rancidity.

A further group of bakery products which has become more popular over the last 15−20 years is the prebaked pastry shell which the baker buys, fills, and sells. These shells include sweetened short and laminated pastries with low water activities and they often use butter as the paste or laminating fat. In such products water activities and moisture contents are low and shelf lives in the prebaked form are longer than would be the case for a freshly prepared shell. They may suffer with rancidity problems if stored for very long periods of time or under unsuitable conditions, including exposure to light.

15.5 Evaluating the Shelf Life of Bread and Other Bakery Products

15.5.1 Sensory Properties

Subjective descriptions of the sensory properties of bakery foods may be used in the evaluation of their shelf lives and some of the key textural properties relevant to cereal-based foods have already been introduced. Staleness is the all-embracing term which is most often used to describe the changes in product textures as they lose their "fresh-baked" character. However, as discussed above, staleness in bakery foods is very product specific and embraces a range of different product properties including moistness, firmness, hardness (softness), springiness, crispness, and so on.

Moistness is directly related to product moisture content while firmness and hardness are generally used to describe a loss of softness in bread and cake crumb. The descriptor softness may be seen as a positive attribute in bread crumb but is seen as a negative attribute for crusty bread products, biscuits, and pastries. Fresh bread crumb is expected to exhibit springiness but cake crumb is not.

Figure 15.5 Consumer squeeze test on bread.

Two key bread characteristics associated with freshness are the softness of the crumb and its ability to recover after the deforming force has been removed. These are most readily assessed with the fingers as shown by the common "squeeze" test applied to packaged bread by consumers (Fig. 15.5). When bread is cold on the retail store shelf, experience and subconscious training by others lead individuals to reject packaged bread which is firm to the touch or remains "squashed" after the squeeze test.

15.5.2 Bread Firmness and Resilience

The most commonly applied methods for objectively assessing bread and cakes use a compression or deformation test in which the product is compressed through a standard distance and the force required to achieve this is measured, or by using a standard force and measuring the distance that the probe will travel in a fixed time. Owing to its cellular structure bread crumb does not obey Hooke's law which means that Young's modulus (stress/strain) varies with the amount of strain, the latter being measured as fractional compression (Cauvain, 2004).

One of the earliest forms of objective measurement was to compress a sample of bread crumb of known thickness between two flat, parallel plates using a standard weight applied for a fixed period of time and recording the distance traveled by the upper plate. The equipment concerned was known as a Compressimeter. A second common form was to compress the sample using a cone with a defined angle (cone indenter). The mechanism of operation was similar to that of the Compressimeter but in this case the compressing weight was carried on a pan suspended below the bread sample with the cone pressing downward through the bread crumb. In the case of both these pieces of equipment additional texture information could be obtained by measuring the recovery or springiness of the sample after carefully removing the compressing force and measuring the height to which the sample recovered within a fixed period of time.

The early forms of bread compression equipment have now largely been superseded by the development of motorized equipment linked with data acquisition and analysis by computer (Cauvain and Young, 2009b). One advantage of this approach is that the compressive force is applied at a fixed rate until the required degree of compression has been achieved, commonly 25% or 40% for bread (AACC, 1987).

An alternative approach is to extract a core of bread or cake crumb of known dimension (diameter and height) from given locations in the slice cross-section and to compress them with a flat plate (Cauvain, 1991). The main advantage associated with this approach is that it is easy to adjust firmness data for variations in sample density and moisture, two properties which have a direct effect on the sensory perception of crumb firmness and so may mask the impact of ingredient and process changes in manufacture.

The consumer squeeze test has been automated with the modern objective version comprising a pair of "fingers" which are used to compress the whole loaf (Cauvain and Young, 2009b). The test may be carried out even when the product is still in the wrapper to make the data more directly relevant to consumer perceptions of firmness.

15.5.3 Crispness

The hardness or crispness of bakery products may be assessed using some form of puncture test with a needle or a small diameter cylindrical shaped probe. The test may be applied to bread crust, pastry products, biscuits, cookies, and crackers. It is especially useful for following changes in crispness which arise from moisture migration in composite products (Cauvain and Young, 2008).

15.5.4 Texture Profile Analysis

Multiple compression tests may also be used to determine a range of bread and cake crumb properties. Texture Profile Analysis (TPA) is a common multicompression technique used with bread crumb and the sample is subjected to two compressions in quick succession with withdrawal of the compressing force after each compression. In essence TPA was designed to simulate the processes of biting and chewing in the mouth and the objective textural parameters were first identified by Bourne (1978) using an Instron Universal Texture Machine and these have become commonly available and measured properties using modern generation texture evaluation equipment with computer data logging and analysis.

15.5.5 Moisture Measurement

The common method for measuring sample moisture content is by a form of an oven drying method (Cauvain and Young, 2008). In general, the higher the moisture content of a baked product, the lower its hardness value (ie, it will be softer).

15.5.6 The Measurement of Equilibrium Relative Humidity (Water Activity)

Product ERH may be measured directly on a sample or may be calculated from ingredient and recipe data. For a detailed discussion of the different techniques involved in the measurement of ERH and its calculation the reader is referred elsewhere (Cauvain and Young, 2008). Product ERH is important in the contexts of water availability for spoilage and in determining many of the quality attributes of bakery products. There are errors associated with the measurement of product ERH, especially when there is insufficient water to ensure that all soluble ingredients in the recipe are in solution in the baked product. The process of baking involves the loss of water and the increased likelihood that soluble ingredients such as sugars will come out of solution in the final product (recrystallization). Thus, measured ERHs on biscuits, cookies, and similar low moisture, high sugar products should be treated with caution.

15.5.7 Methods of Assessing Staling in Bakery Products

As discussed above, softness and a combination of resilience or springiness and chewiness are key characteristics of bread crumb and the loss of these characteristics is most commonly associated with bread staling. It has been recognized for some time that starch retrogradation is a major contributor to these storage changes (Schoch and French, 1947) and it has become common practice to follow bread staling using thermal techniques. The most commonly used techniques are differential thermal analysis and differential scanning calorimetry (DSC), though earlier work on bread staling was carried with X-ray diffraction.

The thermal analytical techniques are based on the principle that when a portion of bread or cake crumb is heated in a sealed pan (to prevent moisture loss), the starch component will melt and in doing so there will be a flow of heat from the sample at a given temperature and this flow of heat can be measured with suitable equipment. The magnitude of the heat flow and the temperature at which it occurs vary according to many factors, not least of which is the crystalline state of the starch at the moment of testing. For a given bread recipe the older the crumb sample, the greater the heat flow because of the increased crystallinity of the starch as the result of retrogradation and because of this close relationship DSC has largely become the method of choice when studying bread and cake staling. Examples of DSC endotherms for fresh and stale bread crumb are illustrated in Fig. 15.6.

More recently the range of techniques used to study bread staling has included nuclear magnetic resonance (NMR) because water plays a critical role in bread staling (Chinachoti, 1998). NMR is a noninvasive technique and unlike the thermal techniques

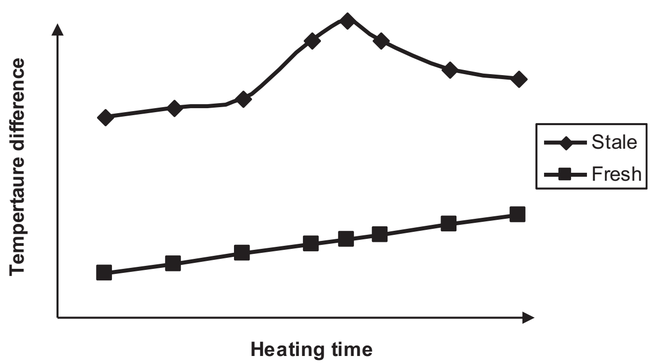

Figure 15.6 Examples of DSC endotherms.

is better able to differentiate between water held in the starch and gluten fractions in bread. This is an important distinction because while the majority opinion is that the amylopectin fractions of the starch are responsible for longer term bread staling there is sufficient evidence to support a view that gluten plays a greater role than previously assumed. In this context the potential for the migration of water at the microscopic level is important in understanding the final dynamics of bread staling (Chinachoti, 2003).

15.6 Ensuring Stability and Extending the Shelf Life of Bread and Other Bakery Products

15.6.1 Controlling Moisture Migration

At the end of baking the surfaces of baked products are sterile. In low moisture products such as biscuits and pastries the low moisture and low water activity ensure that there is limited opportunity for microbial spoilage (provided there is not absorption of water from the atmosphere). The surfaces of cakes and bread are also sterile after they leave the oven but the presence of relatively high levels of water in the crumb presents a different situation than that with biscuits and pastries. The moisture content and water activity of bread crust are usually too low to permit mold growth, but during storage moisture moves from the moist crumb to the drier crumb zone, raising the moisture content and water activity of the latter. In unwrapped bread the moisture evaporates to the atmosphere but for wrapped bread equilibrium is reached among the crumb, crust, and atmosphere in the wrapper surrounding the bread. Collectively the changes result in a reduction of the crumb moisture content and an increase in that of the crust and raise the potential for mold growth. In cake products the equilibration of crust and crumb is even more rapid than that of bread with the result that cakes products are susceptible to mold growth if the ERH is high.

Extending product shelf life by decreasing moisture (and therefore ERH) is not really an option with bread and cakes because of the strong relationship between the moisture content and the consumer perception of freshness as discussed above. In addition in bread it is known that increased moisture in the baked product contributes to reducing crumb staling (see below). Thus, in most cases the extension of bread and cake shelf life will be viewed as the retention of moisture rather than the limiting of microbial growth.

15.6.2 Adjusting Product Water Activity (Equilibrium Relative Humidity)

Since bread and cakes are expected to have relatively high moisture contents an alternative for contributing greater product stability and longer shelf life is to adjust product ERH. Common means of lowering ERH are through the addition of salts, sugars, and polyols. With most bread types the formulation options are limited because the initial ERH is so high and it would be the case that the levels of ingredient addition required

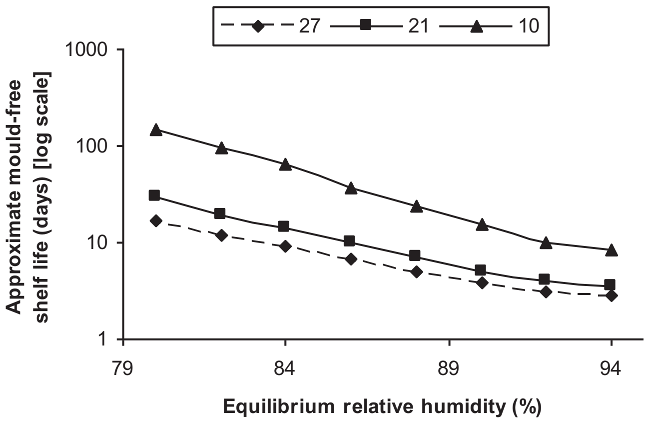

Figure 15.7 Relationship between ERH and mold-free shelf life for bakery products (temperatures are °C; note mold-free shelf life is a logarithmic scale).

to lower ERH and extend MFSL would significantly change product character. The problems of adjusting bread ERH can be appreciated by considering the relationship between ERH and MFSL shown in Fig. 15.7. When stored at 21°C bread with an ERH of 94% has a suggested MFSL of about 3.5 days. If we were to seek to double that MFSL then an ERH of 88% would be needed. Some ingredient and recipe options which might be used to achieve such a change are listed in Table 15.2 together with comments on the likely final product characteristics. It will be recognized from the ingredient effects listed in Table 15.2 that the options for adjusting cake ERH are much greater and an example of how recipe changes can affect MFSL is given in Table 15.3.

ERH not only plays a role in ensuring the microbial stability of bakery products but also plays a major role in controlling the movement of moisture to the atmosphere. In general the lower the ERH the slower the moisture released to the atmosphere by the product. In composite products ERH plays a vital role in controlling the movement of water between components and it is common practice to adjust ERHs to reduce differentials and so limit the driving forces for migration (Cauvain and Young, 2008).

15.6.3 Impacts of Preservatives and pH

The limited recipe options associated with the extension of the shelf life of bread and to a lesser extent cake mean that manufacturers often turn to the use of preservatives as a means of limiting microbial activity. Cauvain (2015) provides a comprehensive listing of the preservatives commonly used with bread and cakes; in general terms propionic acid and its salt and acetic acid and its salts are used with bread while sorbic acid and its salts are used with cake. A particular problem with sorbic acid and its salts is that they have an inhibitory effect on yeast activity and so they cannot be added to the dough without having an adverse effect on dough processing, proving, and baking. One advantage of using sorbic acid in cakes is that the effectiveness of the addition is enhanced when the ERH is lowered (Cauvain and Young, 2008).

Table 15.2 Potential Effects of Recipe Changes to Lower Bread Equilibrium Relative Humidity

Ingredient	Potential for Impact on ERH	Technological Impact	Product Quality Impact
Water	Reduction in level will lower ERH	Reduction in recipe levels will lead to reduced processing efficiency	Shape and internal structure defects, drier eating, more rapid staling
Salt	Increase in level will lower ERH	Inhibition of yeast gassing activity	Salty taste
Sugar	Increase will lower ERH	Some inhibition of yeast gassing activity, softer dough which will be more difficult to process	Darker crust color, sweeter taste, slower staling
Dextrose solids	Increase will lower ERH	Some inhibition of yeast gassing activity	Darker crust color, slower staling
Polyols	Additions will lower ERH	Inhibition of yeast gassing activity	Slower staling

If sorbic acid is used in fermented products then it is common to use an encapsulated form (usually by employing a fat coating) so that the negative effects before baking in the oven can be avoided. Alternatively a solution may be sprayed onto the product surface postbaking, though there are practical problems in ensuring that all product surfaces are adequately covered.

In general the pH range of bakery products will not significantly limit microbial activity during storage; in part this is because of the buffering potential of flour and some of the other commonly used recipe ingredients.

15.6.4 Impacts of Packaging

A key function of the packaging of baked products is to control moisture movement to and from the product. In the case of bread and cakes packaging will be used to limit moisture losses, while with biscuits and cookies it will be used to prevent the absorption of water by the dry product. The movement of water through the packaging will be controlled by the permeability of the material; this is usually expressed as its "moisture vapor transpiration rate" (Cauvain and Young, 2008).

In a few cases controlled moisture loss from the product may be used to preserve the initially crisp eating character of the product. One example would be filled short pastry products where the natural movement of water from moist filling to dry pastry softens

Table 15.3 Modification of Cake Mold-Free Shelf Life by Recipe Change (Based on Cauvain and Young, 2008)

Ingredient	Standard Recipe (weight in g)	Modified Recipe (weight in g)
Flour	100.0	100.0
Sugar	115.0	105.0
Dextrose	0.0	10.0
Whole, liquid egg	85.0	85.0
Fat	65.0	65.0
Skimmed milk powder	8.0	8.0
Baking powder	4.0	4.0
Salt	1.0	2.0
Water	50.0	45.0
Glycerol	0.0	10.0
Product moisture (%)	22.1	20.9
Product ERH (%)	85.5	79.6
Predicted MFSL at 21°C (days)	10	31

the eating character of the latter; controlled loss of water helps lengthen the time for which the pastry stays crisp but does lead to progressive shrinkage of the filling.

The other example where controlled moisture loss is used is with crusty bread products. In this case the approach is to wrap the product in a perforated film. The small holes in the wrapper allow some of the moisture that migrates from the moist crumb to evaporate from the crust, which allows the latter to remain hard and crisp. However, the overall effect of the moisture loss is for the crumb to quickly dry out and become hard. The size and spatial distribution of the holes in the packaging can be very important in delivering the required crust retention (Cauvain and Young, 2008, 2009a).

For bread and cake products significant extensions of MFSL can be achieved using modified atmosphere packaging (Seiler, 1989). The aim with such packaging is to exclude oxygen from the pack and as much as possible from the porous structure of the product and reduce the potential for growth of aerobic microorganisms. The gases employed are usually carbon dioxide or nitrogen, commonly a mixture of both is used with the largest proportion of the gas being carbon dioxide (typically carbon dioxide concentrations will lie in the region of 60−100%). The gas is flushed into the pack of suitably gas-impermeable film and displaces the air. Once the gas exchange is completed the packing film is sealed to retain the gas mixture. Cauvain (2015) gives data for a range of bread and cake products which show that increases of 100% or more could be obtained when the gas in the pack was 100% carbon dioxide.

15.6.5 Limiting Staling (Loss of Freshness) in Bread

Under common storage conditions bread staling which arises because of the intrinsic firming of the crumb cannot be prevented though the rate at which it occurs can be slowed down. The mechanism by which this can be achieved involves changing the rate at which the starch component of the product retrogrades during storage. A reduction in the crumb-firming rate can be achieved through the optimization of moisture levels in the baked product (Zelesnak and Hoseney, 1986). Retention of water within the starch gel will depend on a number of different factors including the retention of water in the product (ie, restricting moisture losses through the packaging effects) and limiting crust formation to reduce moisture migration from the crumb (Cauvain and Young, 2008). The movement of water at the microscopic level between starch and gluten will have an impact on the rate of firming but this will be difficult to influence given that the two components are in intimate contact in the bread crumb.

The most common means of reducing the rate of staling in bread crumb is through the addition of "antistaling" emulsifiers, such as glycerol monostearate (GMS) (Russell, 1983). This emulsifier is thought to complex with both the amylose and the amylopectin component of starch and to slow down the rate at which it retrogrades during storage (Knightly, 1988; Morrison et al., 1993; Eliasson, 1994). The formation of complexes between the high levels of GMS and the linear amylose can lead to excessively soft crumb during cooling and potential problems with pan bread shape (concave sides) and difficulties with slicing. Whatever the precise mechanism by which GMS delivers an antistaling effect, it must be delivered in its most effective form and this is usually considered to be as a hydrate (Moonen and Bas, 2004).

Other emulsifiers (surfactants) can be involved in the reduction of bread staling (Chinachoti, 2003), though some of the mechanisms by which they do this are less clear compared with GMS. This is because commonly used surfactants such as sodium stearoyl lactylate and diacetylated tartaric acid ester of mono- and diglycerides of fatty acids (DATA esters or Datem) play a role in improving gas bubble stability in the dough and gas retention (Cauvain, 2015) as well as having the potential for interacting with both or either the starch and the gluten in the dough (Gaupp and Adams, 2004; Boutte and Skogerson, 2004), though the antistaling effects are limited.

It has become increasingly common to reduce staling in bread crumb using suitable enzyme additions. In part this is driven by the desire of bakers to move to "clean ingredient labels" (in Europe at the time of writing enzymes are classed as "processing aids" and as such do not need to be included on product labels). The addition of enzymes delivers the potential for a crumb softening effect by increasing bread volume; for example, Cauvain and Chamberlain (1988) showed that to be the case with additions of fungal *alpha*-amylase. Thus, care should be taken in interpreting data associated with staling studies used to distinguish between the different effects of enzymes.

The most established enzyme additions for antistaling effects in bread include various forms of intermediate thermal stable or maltogenic bacterial *alpha*-amylases

(Si, 1997). The addition of maltogenic amylase limits recrystallization of the amylopectin in bread crumb during storage, especially the short amylopectin side chains (Goesaert et al., 2009) and thus decreases the rate of staling. The other class of enzymes that have potential as antistaling agents in breadmaking are the lipases (Leon et al., 2002). Early use of lipase was associated with those specific to nonpolar lipids and later introductions have been the phospholipases. In some cases such enzymes may be seen as replacements for the addition of emulsifiers (Rittig, 2005) and this may be through a hydrolyzing effect on the polar lipids and a contribution to the stabilizing of the gas cells in the bread dough (Kornbrust et al., 2012). The claims for lipases as antistaling enzymes are less clear and though there is speculation of in situ generation of monoglyceride-like compounds, convincing evidence has yet to be provided.

It is known that the treatment of bread with alcohol has a significant impact on reducing the rate of bread staling and acts as an antimicrobial agent (Cauvain, 2015). The alcohol treatment is applied after baking and immediately before bagging or sprayed into the bag along with the product before sealing. Limiting alcohol losses with effective sealing of the pack and by choosing a suitable moisture vapor transpiration rate are very important. Some products may be double wrapped to ensure that the alcohol is successfully retained.

It has been known for a long time that bread stales at its fastest at temperatures around 4−8°C (Cornford et al., 1964) so that bread stored in a refrigerator firms faster than bread stored under ambient conditions. Once bread is held below its glass transition temperature, ie, frozen, staling ceases. The temperature at which the maximum firming rate occurs depends on the formulation of the product and it is known that the addition of sugars will retard staling (I'Anson et al., 1990; Cairnes et al., 1991). Thus, fermented products such as rolls and buns which contain more sugar than bread have their maximum firming rate at higher temperatures and in cake products which have even higher sugar levels, the maximum firming rate can be at around 20−25°C. While deep freezing will bring bread staling to a halt, the very act of freezing and thawing is the equivalent of 24 h of bread staling (Pence and Standridge, 1955) because the product must pass twice through the temperature of optimum staling, once on cooling and once on thawing. The overall impacts of applying freezing as a means of ensuring longer term storage stability have been discussed above and are discussed in more detail by Cauvain (1998).

15.7 Future Trends

Loss of freshness (staling) remains a major concern to the manufacturers of bakery products. While much is known about the mechanisms involved, retaining the freshness of bakery products remains a significant challenge. This is because more than one chemical mechanism is involved and several physical factors can also contribute to the changes which occur during product storage. With the introduction of improved abilities to measure the physical characteristics of the structure of fermented products, eg, using image analysis equipment such as C-Cell (C-Cell Limited, Warrington, UK; www.c-cell.co.uk), it is possible to examine more closely the role that crumb porosity plays in the storage stability of bakery products (Cauvain, 2013). In this context an increased understanding of the role of moisture migration though the cell walls and pores of the crumb can offer new insights as to how to use the physical architecture of a product to deliver some of the stability perhaps previously achieved through the addition of functional chemicals.

Specific formulation strategies have been evolving for many products which increase their stability and extend their shelf lives. However, a major problem for the baking industry is that baked products, especially bread, are sensitive to consumer perceptions and retail pressures. This is because baking still largely retains a wholesome, hearth-and-home image and today everyone can bake a loaf of bread if they have an automatic breadmaking machine. This probably means that ingredients lists on bread receive greater scrutiny by consumers and others. Increasingly there is retail and consumer pressure to have and offer "clean-label" products (Cauvain, 2015). This means that functional ingredients such as preservatives and emulsifiers are no longer seen as "desirable" in the product formulation despite their roles with respect to product stability and safety during storage; neither are "chemical-sounding names" or "E numbers" seen in a favorable light. Alternative ingredients for the baking industry are few. In the case of bread, acetic acid (vinegar) has achieved a degree of acceptability not enjoyed by calcium propionate but it does not deliver the same impact as an antimicrobial agent.

Increasingly the baking industry is turning to enzymes in the pursuit of clean-label products. This approach will only be successful as long as enzymes remain processing aids and are not required to be listed on ingredient labels. The primary argument centers around the fact that the enzymes are denatured during baking and as such do not remain in the final product. This argument is weakening, not least because some forms of "antistaling" enzymes are now being offered which survive the baking process and continue contributing to crumb softening during postbaking storage.

Two other factors will have an impact on the future usage of antistaling enzymes. One is the increasing concern with respect to the source of the enzyme. Almost all of the enzymes in modern use, and certainly those used in baked products, are derived from microbial fermentation technology. The competitive nature of the enzyme-producing industry has led to the modification of existing microorganisms to increase yields of ever more sophisticated enzymes with greater specificity in their action. In the pursuit of this goal genetic modification of microorganisms has been used and while no genetically modified material is carried through the enzyme concentrate, such approaches may not satisfy bread purists. The other factor is the potential for allergic reactions to enzymes in flour and mixes. Concern centers on the individuals who handle flour and bakery mixes and this will certainly lead to a degree of openness on the presence of enzymes in bread improvers and the like. Once the "genie is out of the bottle" it will be hard to put it back in.

The pressure to reduce sodium levels in baked products also offers new challenges for bakers. Attention on salt reduction has largely concentrated on the problems facing plant bakers in the preparation and processing of the dough. Salt is a well-known food preservative and while its effects are small in terms of bread stability, if lower salt levels are combined with the reduction/elimination of other preservatives there is no doubt that the shelf life of bread products will decrease. In cake manufacture salt plays a significant role in lowering product ERH with the benefits of longer MFSL and reduced water migration in composite products.

So what are the "nonchemical" options for the baking industry? The main one will be improved temperature control during storage and distribution. However, this is not always the most obvious option as illustrated with bread; while storing bread at refrigerated temperatures will extend its MFSL it will also increase its rate of staling. This has been a particular problem for the sandwich industry since the safe storage of such products requires their refrigeration, which in turn quickly leads to firm and inedible bread slices.

For the purist bakers the answer put forward is to make and sell bread and other bakery products on a fresh, daily basis. This is not the panacea that it seems since consumer shopping habits in many countries have changed since 1965 and a daily trip to the bakery to buy a product which loses its fresh appeal within 24–48 h may not be viewed favorably. Over the centuries bakers have responded to the many challenges placed before them by displaying great ingenuity; there is no reason to suppose that they will not continue to do so.

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