Stanley Cauvain

Technology of Breadmaking

Third Edition

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Preface to the Third Edition

The second edition of the Technology of Breadmaking included many revisions and the same has happened in this edition. There are several drivers behind the preparation of the new edition. The first and perhaps the most expected is that the technology behind the manufacture of bread and fermented products has continued to evolve with new ideas for products and processes, new ingredients becoming available and new equipment made available. Not all new baking technology innovations survive the test of time. There is no real case for arguing that different breads come and go as the 'fashion' driver changes or new consumer trends develop. However, one trend that has become apparent since the second edition was published is that availability of a wide range of products is increasing.

This trend is global in nature but takes different forms in different parts of the world. In countries with a strong cultural base of consuming pan breads, we see a resurgence of interest in traditional or artisan breads. While in other parts of the world where previous consumption was based on flat breads, there is increasing interest in the manufacture of pan breads. Even in countries where staple foods have been rice and noodles, wheat-based products are generating increasing interest.

Increased travel and experience of other cultures undoubtedly plays a part in spreading product concepts and new ideas, but perhaps the greatest influence is the availability of a plethora of information on the Internet. There is hardly a baked product recipe and production method that you cannot find and there can be no shortage of new ideas to try. However, this is a big difference between taking a domestic-style recipe and product and larger-scale manufacture of fermented products. To be successful with the later activities, you need to have an in-depth knowledge of the complex ingredient–recipe–process interactions that characterize bread and other fermented products. My aim in delivering a third edition of Technology of Breadmaking is to continue providing the in-depth technical information to meet the needs of cereal scientists, baking technologists, manufacturers and students, which will lead to even greater innovation in baking.

In revising this edition I wish to acknowledge the contributions made by authors in the first two editions. They have provided me with an excellent platform on which to build the contents of this edition. My thanks therefore go to

Alan Bent, UK.
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I would also like to thank Rosie Clark for helping me with text revisions.

A special acknowledgement goes to the late Linda Young who was not only a contributor but co-editor on the two previous editions. In many ways this third edition is a tribute to her immense support from the moment when the project was first conceived in the mid-1990s and her dedication to completing the second edition while she was ill. In completing this third edition I dedicate it to the memory of Linda Young, co-editor, co-worker and close friend of many years.

BakeTran, Witney, UK Stanley Cauvain

Preface to the Second Edition

The manufacture of any processed food is constantly evolving and breadmaking is no exception. Even though bread has been made for thousands of years and its traditional forms remain as strong today as they did in past times, new ideas and new technologies are being developed and adapted to underpin modern production.

While new technologies will undoubtedly continue to drive developments in breadmaking its traditional basis should not be neglected. Increasing diversity of products in part driven by consumer demand will contribute heavily to the future of breadmaking. More frequent travel and increased global communications expose many more people to the diversity of bread products. What is a traditional product in one part of the world is the novel product in another.

Since writing the first edition of the Technology of Breadmaking the knowledge base on which breadmaking is founded has undergone considerable enlargement and fuelled many of the more recent product and process developments. This second edition sets out not only to update the first edition but also seeks to identify and discuss the new knowledge that has become available in last 10 years or so.

We wish to thank those original authors who willingly gave their time to revise their original contributions.

BakeTran, UK

Stanley P. Cauvain
Linda S. Young

Preface to the First Edition

Not another book on breadmaking! A forgivable reaction given the length of time over which bread has been made and the number of texts which have been written about the subject.

To study breadmaking is to realize that, like many other food processes, it is constantly changing as processing methodologies become increasingly more sophisticated, yet at the same time we realize that we are dealing with a foodstuff, the forms of which are very traditional. We can, for example, look at ancient illustrations of breads in manuscripts and paintings and recognize products which we still make today. This contrast of ancient and modern embodied in a single processed foodstuff is part of what makes bread such a unique subject for study. We cannot, for example, say the same for a can of baked beans!

Another aspect of the uniqueness of breadmaking lies in the requirement for a thorough understanding of the link between raw materials and processing methods in order to make an edible product. This is mainly true because of the special properties of wheat proteins, aspects of which are explored in most of the chapters of this book. Wheat is a product of the natural environment, and while breeding and farming practices can modify aspects of wheat quality, we millers and bakers still have to respond to the strong influences of the environment.

The quality of the baker's main raw material, wheat flour, varies and so special knowledge is needed to ensure the right product qualities are formed in the bread for the consumer. Since some of the most significant changes in wheat quality are related to the environment in which it is grown, a most important tool for bakers is knowledge, without it they cannot adjust recipes or processing methods to ensure consistent product quality.

It is because breadmaking requires constant reaction to 'natural' changes and it has been the subject of scientific and technological study that there is room for another book on the subject. New ideas are being presented to bakers from wheat breeders, millers and ingredient and equipment suppliers, which are coupled with consumer and legislative pressures. These have to be integrated with 'natural' changes.

It is the purpose of this book to provide a useful tool to help bakers, scientists and technologists to cope with those changes. We hope that when you read through the contributions you will find something to make your particular job easier, or even something to enjoy.

As you read through the various chapters there will be occasions when you say to yourself ‘I've read about that before’. When you get different authors to write about breadmaking, they have to consider the same common themes but they will approach them from their own special angles. The most common theme of course is the conversion of wheat to flour to bread. Each individual involved in that conversion process has a contribution to make, but in order for that contribution to be successful they must understand what part they play, and because of this they have different needs in their understanding. These different needs will be evident as they discuss common issues such as gluten development, so

- the cereal scientist seeks to understand the molecular reactions;
- the bakery technologist seeks to apply the understanding and solve bakers’ problems;
- the flour miller seeks to ensure a consistent product by understanding the links between wheat, flour and bread quality;
- the ingredient suppliers seek to understand the contribution of their ingredients to bread quality;
- the equipment manufacturers seek to understand how dough behaviour interacts with their equipment; and
- bakers seek to make bread for their customers.

Editing a book of this type, just like breadmaking itself, is a team effort and so we would like to thank the members of our team:

- The authors of the individual chapters who having agreed to write a contribution discovered like so many before that it is not as easy as it looks when you read a book written by someone else. We thank all of you for patience and perseverance.
- The publishers without whom this book would not have seen the light of day.
- Our many supporters, both moral and material.
- Our scientific mentors.

Why 13 chapters? That is easy to answer—thirteen is the traditional ‘bakers dozen’.

BakeTran, UK

Stanley P. Cauvain
Linda S. Young

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Chapter 1
Bread: The Product

Introduction

Bread in its many forms is one of the most staple foods consumed by humanity. Traditionally bread is based on flour derived from the cereal wheat. Many other types of cereals, pulses and even legumes can be milled to give a ‘flour’ but the ability of the proteins present in wheat to transform a gruel of flour and water into a glutinous mass which becomes bread is currently limited to wheat and a few other commonly used cereal seeds. Genetic manipulation may yet combine the special protein characters of wheat with other more conveniently grown and processable seeds, e.g. no crease or a more rounded shape, but today we are still dealing with a cereal crop largely unchanged, in the genetic sense, from the time that humanity discovered its ability to make a special food many thousands of years ago.

Many consider bread to be one of the oldest, if not the oldest ‘processed’ food. We are unlikely ever to identify the moment when bread was ‘discovered’ though it is likely that the place of discovery was in the Middle East where the origins of cereal farming also lie in antiquity (Zohary 1969). In its earliest forms bread would have been very different from how we see it in industrialized countries today and it would probably be closest in character to the modern flat breads of the Middle East. We will probably never know whether the gathering and cooking of wild grass seeds provided the spur to arable farming or whether the ability to grow and harvest the forerunners of modern wheats provided the impetus for breadmaking. Whichever way round the two events occurred there is no doubt that one depends on the other and this simple relationship is the foundation of all modern breadmaking.

The move to improve the digestibility of the wild grass seed forerunners of early wheat types, by cooking or baking represents a major step in the evolution of human food production. To make this step requires an appreciation, but not necessarily a scientific understanding, of the unique properties of the proteins in the grass seeds we call wheat, namely their ability to form a cohesive mass of dough once the grains have been crushed (milled) and the resultant product wetted (hydrated) and subjected to the energy of mixing, even by hand. This cohesive mass is the one we

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bakers call ‘gluten’ and once formed it has the ability to trap gases during resting (fermentation and proof) and baking and this allows the mass to expand to become a softer, lighter and even more palatable food after the final heat processing.

Another important event in the production of bread was the discovery that, if left long enough, the dough mass would increase in volume without being subjected to the high temperatures of cooking or baking. There is no doubt that the changes in the rheological character of the dough—the way in which it behaved on handling—would also have been keenly observed by those in charge of food production. The combined effect of these changes is for the subsequent baked mass to be further increased in volume and give a product with an even softer, more digestible character and different (improved?) flavour. Gradually the appreciation of the actions of wild yeasts and portions of old dough (e.g. starter or mother doughs) were to lead to the transfer of fermentation technology from the brewing industry and eventually to the production of the specialized bakers' yeasts that we use today.

Bread is a staple foodstuff and today there are few countries in the world where bread and fermented products are not made and eaten. Bread products have evolved to take many forms, each based on quite different and very distinctive characteristics. Over the centuries, craft bakers around the world have developed our traditional bread varieties using their accumulated knowledge on how to make the best use of their available raw materials to achieve the desired bread quality. Commonly this has been by adapting and changing pre-existing processing techniques and on occasions developing entirely new ones. Today, scientific study and technical development provide faster and more cost effective ways of making bread, but even so bakers still have to use their collective knowledge, experience and craft skills to integrate the available raw materials and processing methods to satisfy their customer demands for fresh, wholesome and flavoursome fermented products. While our basic raw material, wheat, is generally much improved in quality and more consistent in performance, it is still a ‘natural’ material and as such is continually subjected to the influence of environmental factors during growth, at harvesting and during storage. All of these factors, and others, such as agronomic practices contribute both individually and collectively to variability in wheat during milling and flour performance during breadmaking.

In some countries the nature of breadmaking has retained its traditional form while in others it has changed dramatically. The flat breads of the Middle East and the steamed breads of China are examples of traditional bread forms which still remain an essential part of the culture of the countries where they are still produced in large quantities. On the other hand in North America the arrival of wheats along with settlers and farmers from Western Europe was to lead eventually to production of new wheat varieties and the rapid industrialization of breadmaking in a country where the maize-based products of the native Americans had previously been the main cereal-based foods.

Today consumers are becoming increasingly cosmopolitan in their taste for bread as the influences of international travel and cultural exchange lead to a wider appreciation of the infinite variety of bread. In the UK for instance, Italian ciabatta, Indian chapattis and French baguette are all eaten along with UK-style sliced bread and there is a resurgence of interest in starter doughs and more classical fermentation technologies. Today the versatility of breads and the ingenuity of bakers means that for those of us who enjoy eating bread there is truly ‘something for all tastes and occasions’.

Quality Characteristics of Bread

The product which we call bread today represents the progressive technical development and improvement of fermented wheat-based products over many thousands of years. In common with most, if not all products of modern life, the evolution of breadmaking processes has progressed further in the last 70 years than in all of the preceding centuries and yet, because it is ‘that most ancient of foods’, it still evokes the most passionate of discussions about quality, taste and value for money. You have only to spend an hour or two in a room with bakers to appreciate just how emotive a subject breadmaking is, a strange mixture of craft, science, technology, art and to many ‘love’.

The proliferation of bread varieties, a few of which are illustrated in Fig. 1.1, derives from the unique properties of wheat proteins to form gluten and from the bakers' ingenuity in manipulating the gluten structures formed within the dough. The rubbery mass of gluten with its ability to deform, stretch, recover shape and trap gases is very important in the production of bread and all fermented products. Of all the cereals wheat is almost unique in this respect. Some other cereal flours, such as those derived from rye and barley, can form gluten but to a lesser extent than normally seen with wheat flours. It is possible to mimic some of the character of

Fig. 1.1 Bread varieties (courtesy *BakeTran*)

wheat-breads with products made from other cereals but if similar volume, crumb characteristics and flavour to wheat-based breads are required then any natural proteins present must be supplemented with other sources of gas-stabilizing ingredients, whether they are protein, carbohydrate or lipid-based.

With such a long history of production and such diversity of form, breadmaking is almost always an emotive subject. Whenever the subject of quality is raised amongst bakers and consumers, we can guarantee that there will be a diversity of opinion, with different bakers extolling the virtue of different breads, different processes, different dough making formulae and different ingredients. In these circumstances it is meaningless to describe bread as being ‘good’ or ‘bad’ (unless there is a genuine quality problem which renders it inedible), since the phrase ‘good bread’ will have a different meaning to each of us depending on our cultural background, our individual experiences and our personal likes and dislikes. For example, there are many supporters of the dense wholemeal (wholewheat) bread that one may typically make at home and they will find the large-volume, soft wholemeal of the plant bakery unacceptable, but the latter form will find greater acceptability in sandwich making for retail sale. It is interesting to note that while the quality characteristics of these two types of wholemeal bread may be very different the nutritional and health benefits, if we ignore any possible differences in digestibility, remain largely the same.

We use the term ‘bread’ to describe a range of products of different shapes, sizes, textures, crusts, colours, softness, eating qualities and flavours. The characters of the products are diverse, and because of this the terms ‘good’ or ‘bad’ quality have no meaning, except to the individual making the assessment. A baguette is not a baguette without a crisp crust while the same crust formation would be unacceptable on North American pan bread. The fine crumb cell structure of sandwich bread in the UK has no relevance to the flat breads of the Middle East. Clearly the ‘ideal’ loaf depends on who you are and where you are. Today we find bread made and eaten in parts of the world where wheat is not an indigenous crop and because of this some of the essential characters of bread have become universal, the form may be different but we all largely seek many of the same attributes from all of our fermented products.

Despite there being as many opinions on what makes ‘good’ bread as there are bakers and consumers it is true to say that certain quality characteristics are required for different varieties to be acceptable to the widest cross-section of consumers. For example, baguettes are characterized by a hard and crisp crust and without it we would reject the product, often describing a baguette with a soft crust as ‘stale’. On the other hand, sliced pan breads in the USA, the UK and elsewhere are characterised by a thin but soft crust, and if the crust were thick and hard it would often be rejected by consumers, ironically, also being described as ‘stale’.

Loss of product freshness is as much about what we expect a product character to be as it is about its age since original manufacture. Whatever the criteria we use to judge bread staleness, it becomes clear that the single most common requirement of fermented products is that it should ideally retain all of the attributes which it had when it left the oven; above all else we expect our bread to be ‘fresh’. When we collect our bread from the baker and it is still warm to the touch we have no doubt as to its freshness but when we purchase it cold from the store shelf we need convincing as to its freshness. The pursuit of fermented products which retain their ‘oven-fresh’ character for an extended period of time after they have left the oven has been one of the great challenges facing bakers, technologists and scientists for many years and many different strategies have been evolved to meet this challenge. Whether they have been successful can really only be judged by consumers.

To be able to make our particular bread type we must have an understanding of the complex interactions between our raw materials and the methods we will use in the conversion processes from ingredients to baked product. Our raw materials will change and our processes are time and temperature sensitive. Given the intricate nature of the process, it is a wonder that we manage to make bread at all. We do so because of accumulated knowledge—craft—augmented these days by scientific and technological understanding.

The Character of Bread

What are the essential characters of breads? How do we distinguish them from cakes, pastries and biscuits? We have already considered that ‘bread’ requires wheat flour (mostly) and water to form gluten to trap the gas generated by the added or natural yeasts. We usually see at least one other ingredient used, namely salt, which is added to give more flavour to the baked product. As will be discussed later, salt not only contributes flavour to bread but it also makes significant contributions to controlling yeast fermentation and dough development. With increasing medical concerns being raised about the level of salt in the average diet, reductions in salt levels are being made. One of the prices to be paid as the result of salt reduction is a change to bread flavour. Not that flour and water, when mixed and baked, with or without yeast, has no flavour since the very action of baking develops flavour compounds in the crust, and natural bacterial and wild yeast actions can also develop flavours within the bread crumb.

To some extent we can argue that a definition of the character of bread can be based on the ingredients used. To many an essential difference between bread and other baked products is that cakes, some biscuits and some pastries contain sugar to confer sweetness (and other less obvious properties), but in the USA bread commonly contains added sugar, as do the sweet breads of India. In addition, where would we place fermented buns and rolls? The other ingredient commonly present in relatively high proportions in cakes, pastries and biscuits is fat. Most breads contain much lower proportions of fat than cakes, but where then do we fit fermented products such as croissant?

The fact is that we can never form a concise definition of bread since it is characterized by all of the ingredients we use to make it, and more besides. An essential component of bread is the formation of gluten, a process which does not occur in cakes to any significant degree and indeed is actively discouraged by the addition of sugar and, to a lesser extent, fat and the use of high level of water addition (Cauvain and Young 2006). Most biscuits and pastries also have limited gluten formation by comparison with most bread products. In laminated products, however, gluten formation is encouraged and bakers have evolved a specialized layering technique to allow the incorporation of fat for the modification of texture and eating quality but without much disruption of the gluten formation, and so we can say that in the case of croissant and Danish pastries, the addition of yeast places the products in the fermented goods category alongside bread.

In seeking a definition of bread we should not overlook the contribution of the water. Its addition in the ‘right’ quantity is essential for the formation of gluten and for modifying the rheology of the dough (Cauvain and Young 2006). The level of moisture remaining in the baked product is also a major contributor to the characters of breads. Too much or too little added water during mixing means that we cannot form the ‘right’ gluten qualities to trap the gases from yeast fermentation. Too little remaining in the baked product will result in the eating character being closer to that of pastries and biscuits.

The character of bread and other fermented products then depends very heavily on the formation of a gluten network in the dough, not just for trapping gas from yeast fermentation but also to make a direct contribution to the formation of a cellular crumb structure which after baking confers texture and eating qualities quite different from other baked products. Look closely at the crumb structures of most baked breads (Fig. 1.2) and you will see that the common linking theme is that they are formed of holes of differing shapes, sizes and distributions, each hole being embraced by a network of connected strands, coagulated gluten, in which starch granules and bran particles are firmly embedded. When this crumb is subjected to pressure with the fingers it deforms (Fig. 1.3), and when the force is removed it springs back to assume its original shape, at least when the product is fresh. This combination of a cellular crumb with the ability to recover after being compressed largely distinguishes breads from other baked products and these are the very characteristics that bakers seek to achieve in most bread products.

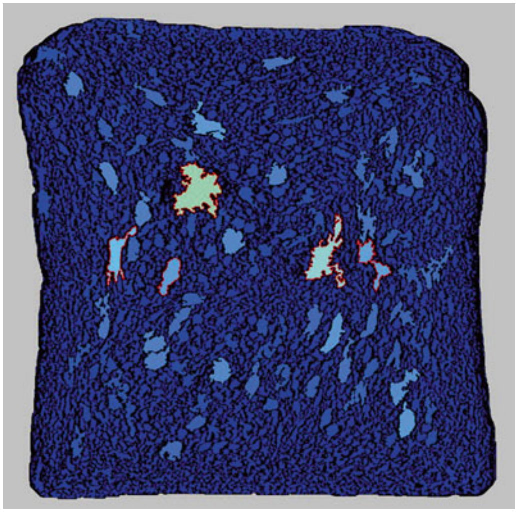

Fig. 1.2 Colour coded crumb structure of bread, images obtained using C-Cell; small cells being *darker blue* with the largest cells (considered to be *holes*) *highlighted in red* (courtesy *BakeTran*)

Fig. 1.3 Sensory analysis of crumb by compression (courtesy *BakeTran*)

Bread Flavour

Nothing will provoke more debate in discussions on bread characteristics than that related to the flavour of fermented products. The judgment of what constitutes the 'right' flavour is another highly personal and emotionally charged issue. Sometimes bread products are eaten alone, but more often they will be eaten as an accompaniment to other foods in a meal or as part of a composite product, so that bread flavours tend to be more subtle than we would encounter in many other foods.

The development of flavour in fermented products comes from a number of different sources and includes contributions from the ingredients and the processing methods which are used. Many of the ingredients which are used in the production of fermented products make a significant contribution to the flavour of the product. Flour tends to have a fairly bland flavour with most of its contribution coming from the oils of the germ (embryo) and bran particles present. Since this is the case, we can reasonably expect that wholemeal, whole-wheat and bran- and germ-enriched white flours will yield bread with more flavour than white flours.

Breadmaking around the world has evolved many dough formulations which use ingredients to confer special flavours which have now become an essential part of that product character. The addition of salt (sodium chloride) to bread is the most obvious of those flavour modifiers, imparting both its own characteristic 'salty' taste and working in the mouth to increase our perception of other flavours which may be present. Since salt levels vary in many products so will our perception of flavour between products. Other common additions include fats, sugars, milk products and milk, each contributing its own special flavour. The level of yeast used in the recipe also makes its own unique contribution to bread flavour.

During the natural fermentation processes which occur in breadmaking new flavour products are generated within the dough (Wirtz 2003). Both the intensity of those flavours and the particular flavour 'notes' which are developed change with increasing fermentation time. The most commonly observed flavour changes are those associated with the development of acid flavours from microbial activity in the dough, which are readily detected in the flavour of the bread crumb. Not all of this flavour activity will come from the addition of bakers' yeast; some will come from wild yeasts and bacteria, especially lactic acid bacteria, which are present naturally in the flour (Cauvain in press). Usually several hours of fermentation are required before there are significant changes to the flavour profile of the bread crumb. Where the breadmaking process being used has no provision for lengthy fermentation times, it is often the practice to develop flavour in a 'pre-ferment', 'brew' or 'sponge' which is later mixed with the remaining ingredients to form the dough for final processing (see Chap. 2).

A most important contribution to bread flavour comes from the process of baking. During this heat-setting stage many of the flavour compounds present undergo major changes; some old ones are lost and many new ones are formed. We most readily see this phenomenon in the formation of a dark, mostly brown crust on the outer surfaces of the dough. These changes are associated with the complex processes commonly referred to as 'Maillard browning' (Perez-Locas and Yaylayan 2010) and many of the compounds are highly flavoured. These compounds are very important to our perception of flavour in many baked foods and views have been expressed that as much as 80 % of bread flavour is derived from the product crust. In an interesting parallel in the bakery world, we have seen the introduction of the so-called 'high-bake' water biscuit, confirmation of the contribution that browning of the crust makes to flavour and quality.

The perception of flavour in bread is, then, no simple matter. It will, for example, be strongly influenced by the ratio of crust to crumb. The development of Maillard browning products during crust formation may help us understand why products as different as UK sandwich bread and French baguette have different flavour profiles. In the case of baguette, the proportion of crust to crumb is much higher, so that we will have a larger quantity of compounds which contribute to product flavour. The lower proportion of flavour compounds in UK sandwich bread may be seen by some as being to its detriment, but then the character of the bread is aimed at a completely different end use to that of the baguette and so does require a different flavour profile.

Bread Types

The development of particular types of bread has taken different directions in different parts of the world. As a consequence, not all of the terms used to describe breads and their quality attributes have the same meaning in all parts of the bakery world and this sometimes leads to misunderstandings between individuals regarding bread quality. The most obvious of examples are references to French breads which in the

UK tend to be used to refer to baguette styles while in the USA the same term may refer to pan breads with lean (i.e. low-fat) formulae, such as might be used in the production of French toast. In France the concept of ‘French’ bread as viewed in the UK would not be widely understood. Similarly, the term ‘toast breads’ will have different meanings in France, the USA, the UK and elsewhere. We must recognize that the use of bread quality descriptors and product terminology will be strongly linked with local consumer preferences and traditions, even though in general the terms used to describe the quality attributes of fermented products can mostly be related to the categories of external and internal characters, eating quality and flavour as discussed below.

The characterization of a particular bread type will always include a description of its physical appearance, usually starting with its external form. Thus baguettes are likely to be described by their length and diameter, other bread forms by their pan shape, Middle Eastern and traditional Indian breads as ‘flat’ (Fig. 1.4), and so on. Even markings on the surface may require definition, in the way that the number and direction of cuts on the dough surface may become an integral part of the traditional product character. A comment on the product crust colour may be included. Almost certainly a description of the interior appearance follows with references to the sizes, number and distribution of holes in the crumb and the colour of that crumb. Comments on crust hardness and the eating qualities of the crumb will almost certainly be made and there is likely to be some reference to the flavours present. To help with the characterization there may be references by the describer to other bread types, such as ‘flatter than…’ or ‘with more holes than…’.

How often do we take a few moments to ask ourselves fundamental questions about the character of bread products such as ‘Why is a baguette the length and shape it is’? The very attributes which characterize baguette or any other particular type of

Fig. 1.4 Naan bread from India (courtesy *BakeTran*)

bread were identified many years ago and have become enshrined in our perception of the required product quality for a given loaf. For example, whoever heard of a baguette baked in a round pan? There is no reason why we should not make pan breads with crisp crusts and open-cell structures like those we normally see in baguette, but even if we do it is most unlikely that we would try to call it a baguette because most of our customers would not recognize it as such; essentially they would not view the product as ‘authentic’. In discussing the technology of breadmaking we must recognize that most bread types are the product of long-forgotten traditions rather than the systematic development to give a specific product character.

Reference has already been made to the techniques of cutting the dough surface before baking. Such markings have become part of the traditional character of many breads, like baguette, coburgs, bloomers (Fig. 1.5) and cottage loaves (in the UK). As well as providing a distinctive appearance they also play a significant role in forming many aspects of product character. In some products the cutting of the surface exposes a greater surface area to the heat of the prover and the oven and thereby improves expansion in both of these stages (Cauvain and Young 2001). In the oven the product may expand in a more controlled manner if the surface has been cut, and this may improve the overall product shape. This effect is readily observed in the inclination for the upper part of cottage loaves to become displaced during baking if the lower part has not been cut correctly before entering the oven.

The depth and direction of cutting contributes to the expansion and ultimate volume of a product, an effect best illustrated by once again considering the baguette. The ‘traditional’ French baguette is given a fixed number of shallow cuts, largely following the length of the dough piece (Fig. 1.6), while in other parts of the world more numerous cuts may be made across the breadth of the dough piece. The first technique encourages the retention of much of the gas in the dough and

Fig. 1.5 Distinctive *surface cuts* on a UK bloomer (courtesy *BakeTran*)

Fig. 1.6 *Surface cuts* on baguette

confers greater expansion during baking while the latter technique is more readily inclined to release gas during baking and give a smaller volume in the final product, but of course calls for less skill on the part of the baker.

Such comments are not intended to denigrate or glorify any particular bread product, rather to show the traditional basis of the many bread types we encounter. There are a few relatively modern bread developments and most of our bread types have a long period of development. However diverse our bread types are, they share a number of common elements largely based on the formation of gluten as discussed above and in more detail in later chapters. There are two main elements to bread; the crust and the crumb. The physical form of both crust and crumb and the ratio of one to the other are the very essence of what distinguishes one type of bread from another. The size and the shape of the loaf, together with the ingredients used, contribute to the overall quality but arguably such contributions are of lesser importance to bread character than those made by the nature and proportions of the crumb and the crust.

While we as scientists, technologists, bakers and consumers can earnestly debate the relative merits of crisp and soft bread crusts, we should not lose sight of the contribution that crumb structure makes towards these aspects of bread quality. The crisp baguette crust forms in part because of the open cell structure created in the dough during processing and baking, while a fine, uniform cell structure is essential for the pan breads and must be created at the beginning of the process, principally in the mixer. Achieving the ‘right’ bread quality calls for the creation and control of gas bubbles in the doughmaking, moulding, proving and baking processes. These bubble structures eventually become the bread cell structure when the dough mass is heat set during baking.

The many different bread types which have been evolved with the passage of time all require their own individual bubble structure, processing techniques, processing equipment and process control mechanisms. It is an understanding of each of these factors against a background of an ever-changing raw material quality which allows bakers to maintain traditional bread qualities and to develop new ones in a changing market place. The challenges are many but the manufacture of ‘good’ bread still remains a pleasure for those of us involved in its production.

Assessing Bread Quality

The process by which bread quality is determined still relies to a significant extent on subjective assessments by experts because of the difficulties associated with objective measurements of some highly ‘personal’ characters in breads. The most obvious examples of the assessment problems we face are those characters related to flavour and eating quality because of the diverse preferences of individual consumers. Nevertheless if we as bakers, technologists and scientists are to be in a position to assess the effects of new ingredients and processing methods, to match more closely bread quality with consumer requirements or to reduce product variability and limit quality defects, then we must have some basis on which to make our quality judgments. To state simply that a particular change of formulation has ‘improved’ bread quality is inadequate for others to judge the success of our efforts or for us to make longer-term assessments. We therefore need to have objective criteria and in cases where this is not possible we need to standardize as much as possible the methods we use for our subjective assessments.

Various scoring techniques are usually employed to try and standardize subjective assessment (e.g. Kulp 1991). The attribution of particular numbers will be based on individual requirements. Photographs or diagrams with attribute scores are often used as the basis for comparison between test and standard by the observer. In this way uniformity of scoring is improved and ‘drifts’ in quality perception over a period of time can be minimised.

The techniques for assessing bread quality usually fit into three broad categories: external, internal and texture/eating quality, which includes flavour.

External Character

Among the characters we most often assess under this heading are product dimensions, volume, appearance, colour and crust formation. The critical dimensions for most breads are their length and height, with breadth being of lesser importance. A large number of bread types are characterized by their length, for example baguette which should be 700 mm long in France. Devices for measuring product dimensions off-line can be simple and can include graduated rulers and tapes. It is possible to measure product height and shape on-line using image analysis techniques (e.g. Dipix Europe Ltd., www.dipix.eu) and so provide useful process control data (see Chap. 7). Measurement of height will often be used together with width (breadth) as a basis for an estimation of volume where the product shape makes such estimates meaningful, for example with rectangular pan breads (Fig. 1.7).

The most common method of assessing whole product volume is by using a suitable seed displacement method. The apparatus concerned usually comprises a container of known volume, which has previously been calibrated with a suitable seed, usually rape seed or pearl barley (Cogswell 2008), into which the product is introduced. The seed is reintroduced and the product displaces a volume of seed equivalent to its own volume.

Fig. 1.7 Pan breads; *front*, farmhouse; *rear left*; wholemeal; *rear right*, white sandwich (courtesy *BakeTran*)

It is important to keep such apparatus regularly calibrated with suitable 'dummy' products of known volume since the bulk density of seeds may change with time because of frictional attrition. More recently laser scanning of products has been introduced as a means of assessing product volume (e.g. BVM Volume Measurement, www.Perten.com).

Image analysis techniques have been applied to the measurement of product volume. One such method is based on the measurement of the cross-sectional areas of several slices from selected places along the length of the loaf and then integrating these with the known length of the product. This method may be preferable where uncut loaves are not available and samples are being taken straight from the production line. For products where straight sides are important (e.g. Sandwich breads baked in a pan) deviations from straightness can be measured with image analysis tools like C-Cell (Fig. 1.8)

The external appearance of the product will often be a major factor which attracts the eye of the consumer. To this end, cutting or marking of the surface, both in terms of the number and direction of the cuts must be consistent with the product 'norm'. Any quality assessment of this character can be carried out by comparing the product with a standard illustration of the accepted product norm.

Often the contrast between the darker crust and lighter areas which expand later in baking are seen as desirable quality attributes. This particular aspect is best seen with baguette and other cut and crusty breads. This expansion during baking is often referred to as 'oven spring' or 'oven jump' and in most products should be controlled and uniform, uncontrolled oven spring often being seen as a quality defect (e.g. 'flying' tops or 'capping' in pan breads (Fig. 1.9)). With pan breads, oven spring can be

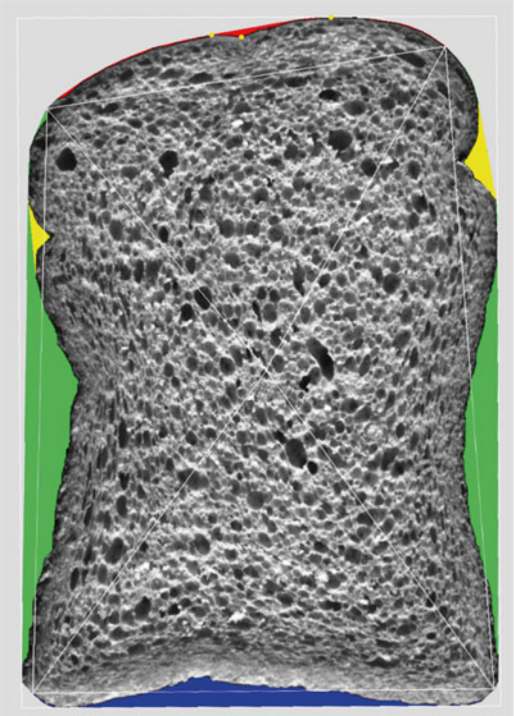

Fig. 1.8 Pan bread image with deviations from straightness (concavity) noted (courtesy *BakeTran*)

Fig. 1.9 Flying top or capping of bread because of underproof of the dough (courtesy *BakeTran*)

calculated directly by measuring dough piece height before entering the oven and loaf height after leaving the oven. In other products a subjective judgment will be used. A subjective judgment on the evenness of the break or 'shred' may also be made.

Crust colour is commonly assessed using descriptive techniques. Objective methods can be used based on comparison with standard colour charts, such as the Munsell system (Munsell undated), or direct measurement with tristimulus type instruments (Anderson 1995), but commonly crust colour is uneven on bread surfaces and this reduces the effectiveness of such measurements to describe the overall surface colour. The presence of unwanted surface blemishes may be noted and included as part of the loaf quality score.

The desired crust character varies with the product and is most often assessed subjectively. Instrumental methods based on puncture (Cauvain 1992) or snapping (Cauvain and Young 2009) may be used, but are not common because the measurement so obtained will be strongly influenced by the complex architectures of the products.

Internal Character

Our major concerns with internal character are normally limited to the sizes, number and distribution of cells in the crumb (crumb grain), the crumb colour and any major quality defects, such as unwanted holes or dense patches, visible in a cross-section of the product. As discussed above, each bread type has its own special cell structure requirements and therefore there is no single standard which can be applied to all products. Because of this, subjective assessment of product crumb cell structure is still the most common method being used with some form of standard reference material, such as photographs. The assessment of crumb cell structure may well also include an evaluation of the thickness of cell wall material, i.e. the crumb structure between the air cells. The information is commonly noted on some form of scoring sheet and there are many examples in the literature (Cauvain and Young 2001; Sutton 2002).

While being among the most important of bread characters, crumb cell structure remains the most difficult to quantify in a way which correlates well with the human perception of quality. Techniques employing photographs, or scanning with video cameras coupled with image analysis, may be used to provide more quantitative data on the cell structure and have been correlated with expert assessors (Jian and Coles 1993; Rogers et al. 1995) More recent imaging systems have evolved which provide a wider range of objective cell structure data (Whitworth and Cauvain 2005) which can be used directly to measure bread qualities (Cauvain and Young 2010; Cauvain 2013). One such instrument is C-Cell (Calibre Control International, www.C-Cell.info) which provides a range of coded images (see example in Fig. 1.2) and quantified data on shape (Fig. 1.8) and cell structure. The assessment of crumb colour may be subjective and descriptive or carried out by objective means using tristimulus colorimeters.

Texture/Eating Quality and Flavour

Texture and eating quality are important properties of bread products and are different from one another. In assessing the texture of bread crumb we are concerned with its mechanical properties such as firmness and resiliency, and often we try to relate such properties to eating qualities by adaptation of more fundamental physical testing methods.

Crumb softness or firmness is the texture property which has attracted most attention in bread assessment because of its close association with human perception of freshness. In the subjective 'squeeze' test (Fig. 1.10) we simultaneously and subconsciously measure a number of product properties. The most obvious of these is the resistance of the product to deformation. Less obvious are how much the product recovers after the deforming force is removed and how much force we need to apply to compress the product to our 'standard squeeze'. Collectively, our subjective assessment will be recorded in degrees of softness or hardness, and sometimes as recovery or springiness. This consumer evaluation method has now been replicated to some degree by an objective measurement (Cauvain and Young 2009).

There are numerous objective methods which have been applied to the assessment of bread texture (Cauvain 1992, 2004). Compression tests form the bulk of such testing methods and mainly cover the measurement of softness or firmness (AACC 1995a, b) and recovery or resiliency (Cauvain and Young 2009). Usually force levels in such tests are insufficient to rupture the crumb matrix to any significant degree and the product will largely return to its uncompressed form after

Fig. 1.10 Consumer squeeze test of freshness (courtesy *BakeTran*)

removal of the compressing force. Such tests mimic to a large extent the subjective assessment of crumb texture made by the fingers during squeezing or compression.

In the process of eating the forces in the mouth will be large enough to cause irreversible changes to crumb properties. In addition to the strong compression and shearing forces the action of saliva and the mechanical effects of chewing patterns form the basis of a method of assessment very different to that applied with the fingers and hand in the squeeze test. Subjective assessments of eating quality are carried out by individuals or groups with scoring based on descriptive terms (Amerine et al. 1965). The application of taste panel techniques for assessing eating quality has received much attention and details can be found in many standard works (e.g. Stetser 1993). Objective methods for assessing eating quality in the mouth are clearly difficult, although electromyography (Eves and Kilcast 1988) has been tried with some foods.

Texture profile analysis (TPA) is one technique which tries to use a common basis for both subjective and objective assessments of product eating qualities. TPA uses seven basic descriptors for eating quality derived from subjective assessment of a wide range of foods (Szczesniak 1963a, b) and which have been subsequently translated to permit objective instrumental measurements (Bourne 1978; Szczesniak 1972). The objective technique uses two successive compressions on the same sample with forces which cause some irreversible changes to the food being tested. TPA has been applied to the assessment of changes in bread eating quality with varying degrees of success (Cauvain and Mitchell 1986).

Evaluation of the flavour in bread products relies entirely on subjective assessments by individuals or groups (Stone and Sidel 1985). The flavour of both crust and crumb may be assessed separately. Standard descriptors for flavour are commonly used but the provision of a standard against which to make such subjective flavour judgments will be difficult and it will be necessary to rely on comparisons or ‘flavour memory’, even with trained panels and agreed descriptors.

Nutritional Qualities of Bread and Its Consumption

Bread and other cereal based products have become ‘staple’ foods throughout the world and are now established as an integral part of many modern diets. The nutritional qualities of cereals are well established, with most of the nutritional input from this category coming from wheat-based products. Although there will be some small changes in the nutritional qualities as a result of the milling and baking processes, wheat-based breads continue to provide significant sources of protein, complex carbohydrates (mainly starch), fibre, vitamins and minerals. The nutritional contributions are greatest in wholemeal (wholewheat) breads since they require conversion of 100 % of the grain into flour. In lower-extraction white flours the removal of some of the bran and germ components from the wheat grain changes the overall nutritional qualities of the resultant product, although in spite of this, white breads continue to make significant contributions to the diet. Typical nutritional compositions for UK breads are given in Table 1.1.

Table 1.1 Composition of bread (per 100 g)

	White	Wholemeal
Carbohydrate	49.3	41.6
Protein	8.4	9.2
Dietary fibre	2.7	7.1
Fat	1.9	2.5

There is a growing trend in some parts of the world to produce breads with characteristics which are intermediate between white and wholemeal. This may be simply accomplished by mixing white and wholemeal flour in different proportions. The most common mix being equal quantities with marketing (but not legal) descriptions such as 50–50 and Best of Both. White fibres from white wheats (i.e. less red coloured bran) are also being increasingly used, especially to encourage an increase in fibre intake in children. The concept of wholegrain breads has developed in the USA and often involves the addition of non-wheat grains, seeds and pulses. This is another example of the attempt to increase the nutritional value of breads, especially with respect to fibre intake. Making health claims with respect to bread products is a complicated business and is usually strictly controlled by local legislation or codes of practice.

Because of the significant role that bread products play in contributing nutrition to the diet, it has become the practice in many countries, e.g. the USA and the UK, to enrich white and some other flours with additional nutrients (Ranhotra 1991; Rosell 2012). The enrichment mainly comprises the addition of calcium, in some form, some of the essential vitamins and a readily assimilated form of iron, although other additions may be possible depending on the regulatory conditions in particular countries, e.g. folic acid (Rosell 2012). The other ingredients used in breadmaking formulations will also make contributions to the nutritional qualities of the products. Some, such as fat and to a lesser extent sugar, may not be considered to be adding to the nutritional value of the food, but in many bread products their levels of addition are modest and so the overall nutritional contribution is small. In some quarters the reduction of bread sodium levels has been advocated, the sodium coming mainly from the addition of salt (sodium chloride) which is used to improve the palatability of bread (see below).

The level of bread consumption varies around the world and from region to region. In the so-called ‘Western’ diets of Europe and North America bread consumption has been declining but not uniformly with bread type or region. The per capita consumption figures for bread products are published for many countries and tend to show the same gradual decline in consumption, even for traditionally ‘large’ consumers of bread product, such as Germany and France. An example of the decline in bread consumption is given for the UK by the data in Table 1.2. However, it should be noted the data which are used to produce such consumption statistics are often influenced by the methods used for data collection; for example, not all statistics take into account bread products consumed out-of-the home and there are often imbalances in the definitions of bread. The UK data are not unique with similar falls in consumption even in countries with a traditionally heavy consump-

Table 1.2 UK household consumption of bread (kg per capita per annum)

Calendar year	Kg
1985	45.86
1990	45.70
1995	39.36
2000	37.44

Source: UK National Food Survey 2000; MAFF 2001

tion of bread products. For example, a recent survey in Italy (Anon 2014) shows that the annualized consumption per head was close to 84 kg in 1980 (daily consumption being around 230 g) but by 2013 this had fallen to less than 36 kg. In contrast the consumption of wheat-based products in Asian regions (e.g. Indonesia) is increasing rapidly, often at the expense of rice consumption (Donley 2014). Whatever the manner in which the statistics are collected and analysed it remains clear that the consumption of bread and other cereal-based products continues to makes significant contributions to human dietary needs throughout the world, and so their continued or increased consumption should be encouraged.

Increasingly the types of bread being manufactured and eaten are influenced by the medical professionals and nutrition lists. For example, wholemeal breads, including rye, are seen as a 'natural' source of folates in the diet while in other cases the enrichment of bread with selenium is seen as having positive health benefits. The latter arises because wheats grown in some parts of the world, e.g. Canada, are naturally higher in selenium and much of the mineral finds it way through to the final flour. Thus in some geographical areas where the local soils are low in selenium there is interest in the potential for fortification, whether at a voluntary or compulsory level. The decision to legislate for compulsory fortification of bread with any material is seldom straightforward. In part this arises from the emotive nature of consumer to bread which is seen as naturally 'wholemesome' and should not therefore have lots of additives however apparently beneficial they might be. So-called food-journalists in the 'popular' press in some parts of the world are never slow to draw attention to the long list of 'additives' used in 'mass produced' bread and all the negative connotations associated with them without considering the positive health benefits which come with bread consumption (e.g. fibre) or that legislation compels millers and bakers to make some additions to the flour and bread. The other problem with additions of ingredients to promote health is that in many cases the medical benefits are only applicable to some sectors of consumers.

The baking industry has made positive reactions to consumer concerns to *trans* fats in the diet following the release of medical evidence which suggests that they should be reduced or even eliminated in the diet. Many bread products already have low levels of added fat in the recipe and in many cases the *trans* fat component has been eliminated from the formulation. Coupled with the reduction of *trans* fat in the diet has been interest in supplementing breads with *omega* 3 rich oils. The key to making changes to the levels and types of fats added in breadmaking is an understanding of their technical function and this is discussed in Chap. 3.

Organic farming and the sale of its products has developed into a mature market sector and includes wheat-based products (Cauvain 2003). The technology of bread production using organic wheats and flours remains very similar to that of the 'non-organic' equivalent though some adjustments to the formulation and processing methods may be required in order to achieve acceptable product quality. There is no consensus view on the nutritional or health benefits of organic products.

The concept of increasing fibre in the diet by consuming cereal-based foods has been in 'vogue' for many years and certainly influenced the move in some countries from white to wholemeal bread consumption. Increasing the consumption of fibre and whole grains is seen as a means of reducing a range of medical conditions including coronary heart disease, some forms of cancer and type 2 diabetes (Miller Jones 2005). Increased whole grain consumption is seen as a positive contribution to reducing obesity. In this respect the increased consumption of bread flies in the face of the dieting trend of recent—e.g. the Atkins Diet—which advocated a reduction in the consumption of carbohydrates. This particular dietary trend has largely passed but not without its impact on the bread industry, especially in the USA where bread consumption fell dramatically while the diet was in vogue. The knock-on effect of such diets was to generate a greater focus on the role of carbohydrates in the diet and along with it the role of bread in the diet. Attention shifted to the concept of the effect of carbohydrate on blood sugar levels and the potential impact on diabetes and obesity. The concepts are covered by the terms *Glycemic Index* (GI) and *Glycemic Load*. Much research has focused on GI (Brennan et al. 2005) and new products have reached market places around the world but the introduction of the GI concept and these new products has yet to result in a dramatic increase in the consumption of bread. While consumers require food to be healthy it is an interesting question as to whether they will see breads as being a means to deliver 'medicines'. For the baker the challenge is not only to provide a nutritious and safe food but one which consumers will readily choose and enjoy. If bread is to be seen as a means of delivering 'positive' health benefits then the first task is to get consumers to purchase and eat the product.

One sector of the bread market which has developed significantly in recent years is that related to the manufacture of gluten free products. The need for gluten-free bakery products was originally to meet the needs of individuals who were medically diagnosed with coeliac disease—a digestive allergy associated with the consumption of gluten-forming proteins. In addition to sufferers of the coeliac condition there are individuals who consider themselves to be 'wheat-intolerant' and seek to reduce or eliminate wheat-based products from their diets. The evidence for wheat intolerance is equivocal but interest in wheat reduced diets has also fuelled the market for gluten-free products. This area of breadmaking is considered in Chap. 13.

Conclusions

The manufacture and consumption of bread is global and products are even made for consumption in space. The use of wheat and other grains for the production of bread has a long history in many parts of the world. In some countries the use of wheat to provide a basic and staple food has a shorter history but has become quickly and clearly established. With a long history of production in diverse cultures, many different types of breads have been evolved and new variations continue to be developed to meet consumer demands for more varied and nutritious foods.

Bakers have developed an almost infinite variety of breads and production methods to meet consumers' needs and must achieve consistent product quality to maintain their markets in the face of increasing competition from fellow bakers and other forms of ‘convenience’ foods. In real terms, bread has always been a convenience product or part of one for the consumer. Because of the diverse nature of bread there is no right or wrong for product quality as each bread type requires its own suite of attributes to be authentic. Having identified the quality of the product which will most satisfy their customers’ needs the challenge for bakers is to use their knowledge of their raw materials and processing methods to achieve that quality and to do so consistently.

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Chapter 2
Breadmaking Processes

In the same way that different bread varieties have evolved with the passage of time so have different methods which allow the conversion of flour and other ingredients into bread. In many cases the relationship between product and process is so strong that it may be wrong to consider them as separate issues. Just as there is no ‘ideal’ product so there is no ‘ideal’ breadmaking process. In reality each baker uses a breadmaking process which is unique, in that the combinations of ingredient qualities, formulations, processing conditions and equipment reflect the qualities of the products he or she is seeking to achieve. In practice many of the variations in such breadmaking processes are very small and usually consist of minor variations about a central ‘standard’ process, so that we are able to group many of the variations into a small number of more generic processes in order to consider the changes which occur within them and their contribution to final product quality.

Functions of the Breadmaking Process

All of the processes which have evolved for the manufacture of bread have a single, common aim, namely to convert wheat flour into an aerated and palatable food. In achieving this conversion there are a number of largely common steps which are used.

- The mixing of flour (mainly wheat) and water, together with yeast and salt, and other specified ingredients in appropriate ratios.
- The development of a gluten structure (hydrated proteins) in the dough through the application of energy during mixing, often referred to as ‘kneading’.
- The incorporation of air bubbles within the dough during mixing.
- The continued ‘development’ of the gluten structure created as the result of kneading, in order to modify the rheological properties of the dough and to improve its ability to expand when gas pressures increase because of the generation

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of carbon dioxide gas in the fermenting dough. This stage of dough development may also be referred to as 'ripening' or 'maturing' of the dough.
- The creation or modification of particular flavour compounds in the dough.
- The subdivision of the dough mass into unit pieces.
- A preliminary modification of the shape of the divided dough pieces.
- A short delay in processing to modify further the physical and rheological properties of the dough pieces.
- The shaping of the dough pieces to achieve their required configurations.
- The fermentation and expansion of the shaped dough pieces during 'proof'.[1]
- Further expansion of the dough pieces and fixation of the final bread structure during baking.

The main differences between individual or groups of breadmaking processes are usually associated with mixing and kneading, air incorporation, and the creation and development of the gluten structure, in summary all of those operations which in practice deal with the formation of a large dough bulk. The subdivision of the bulk dough and the processing stages for individual dough pieces do contribute to the modification of product quality but tend to build on the dough development created before subdivision of the bulk dough. The processing stages at the end of the sequence, proving and baking, are common to most breadmaking processes and differences between individual bakeries tend to be in the type of equipment used and small variations in conditions which are applied in the bakery equipment, e.g. time and temperature.

Dough development is a relatively undefined term which covers a number of complex changes in bread ingredients which are set in motion when the ingredients first become mixed. The changes are associated with first the formation of gluten, which requires both the hydration of the proteins in the flour and the application of energy through the process of kneading. The role of energy in the formation of gluten is not always fully appreciated and is often erroneously associated with particular breadmaking processes, especially those which employ higher speed mixers and short processing methods (e.g. the Chorleywood Bread Process).

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[1] *The terminology used in baking can be confusing for many. This is especially true of two terms; fermentation and proof. Fermentation refers to the action of baker's yeast in the dough on the sugars which are present with the subsequent evolution of carbon dioxide gas and small quantities of alcohol. Fermentation will occur in the dough whenever the conditions are 'right' for the yeast (mainly the availability of food and an appropriate temperature). There are two main times when fermentation occurs; after the dough has been mixed and before it has been divided into unit pieces and after the dough has been finally shaped and before it enters the oven. The former is most commonly referred to as 'bulk fermentation' or simply fermentation, while the latter is most commonly referred to as 'proof'. This change in terminology logically allows the baker to understand which part of the process the dough has reached. In both cases 'fermentation' in the true sense occurs though the temperatures at which the stages are carried out are different with proof commonly being carried out at a higher temperature. A further complication is that bakers may refer to 'first' or 'intermediate' proof to define a short rest period which occurs after first moulding and before final moulding.*

Anyone doubting the validity of the need for energy in gluten formation should try a simple experiment which involves placing flour, water, yeast and salt together on a table and waiting for the gluten to form. They should then be encouraged to begin hand mixing of the ingredients to experience the transformation in the mixture which will occur. The best results in terms of improved bread volume and crumb softness will be achieved with vigorous and prolonged hand mixing and kneading. During the process of kneading, the dough, and more probably the ‘baker’, becomes warmer as energy is imparted to the dough. However, there is more to dough development than a simple kneading process.

In the process of developing a bread dough we bring about changes in the physical properties of the dough and in particular we improve its ability to retain the carbon dioxide gas which will later be generated by yeast fermentation. This improvement in gas retention ability is particularly important when the dough pieces reach the oven. In the early stages of baking before the dough has set yeast activity is at its greatest and large quantities of carbon dioxide gas are being generated and released from solution in the aqueous phase of the dough, along with steam and thermal expansion of the trapped gases. If the dough pieces are to continue to expand at this time, then the dough must be able to retain a large quantity of that gas being generated, and it can only do this if we have created a gluten structure with the correct physical properties.

Four physical properties of dough will concern us in breadmaking: resistance to deformation, extensibility, elasticity and stickiness. We can use the analogy of an elastic band to help understand the first three of these properties. When we stretch the elastic band in our hands a degree of force is required to change its shape as it resists deformation. If we apply only a modest force and release one end of the band then, because it is an elastic material, it returns to its original shape. If we once again stretch the elastic band and continue to apply force without releasing it we will eventually reach a point of extension when the elastic band snaps, which we could take as a measure of its extensibility. The fourth physical property, stickiness, is largely self-explanatory. After some materials have been compressed they will stick to the surfaces within which they are in contact, so that when the direction of the compressing force is reversed they exert an adhesion force before parting from the surfaces concerned.

Dough stickiness is the least desirable property for the baker because it makes dough processing difficult. This is especially true in plant bakeries where the tendency for the dough to smear onto the surfaces of processing equipment leads to an accumulation of dough material which eventually impedes the progress of dough pieces and may bring the plant to a halt. Yet dough is not in itself sticky but becomes so when it is subjected to stress and shear. The effect of the latter is especially important and occurs when blades are driven through dough (e.g. during dividing of the bulk dough into unit pieces) or when a surface of the dough is moved at a different rate to its bulk (e.g. during mixing and moulding). Typically the stickiness observed with dough immediately after it has been sheared will reduce with even a short resting time. Because the rheology of dough changes with a short rest or further manipulation and this has made the objective assessment of stickiness’ difficult

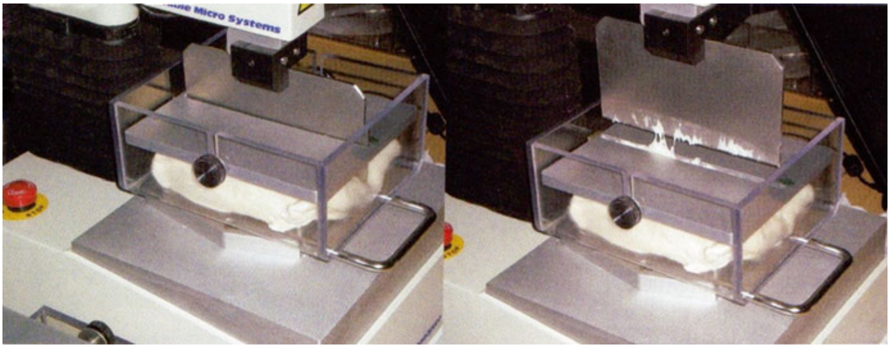

Fig. 2.1 Dough stickiness test (Courtesy *BakeTran*)

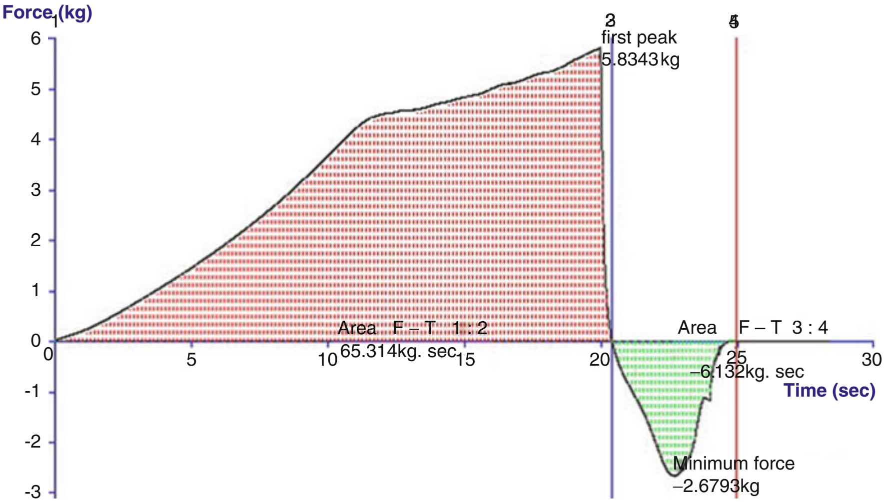

Fig. 2.2 Typical output from the dough stickiness test (Courtesy *BakeTran*)

to achieve. The recent introduction of a new stickiness test (Cauvain 2012) may help better understand what contributes to stickiness in dough (Figs. 2.1 and 2.2).

A common reaction to dough stickiness is to reduce the dough water level in the mixer. While this may improve the handling of the dough it does not necessarily reduce its overall stickiness by much. Doughs which are under-developed are more prone to the effects of shear, and optimised water levels are an important part of delivering optimized dough development. In addition, lower water (stiff) doughs tend to have a greater resistance to deformation and a tendency to be more elastic. This often means that greater pressures need to be applied during dough processing during moulding and can lead to the damage of gas bubble structures in the dough which show in the final product as areas of coarse structure, or even unwanted large holes in the crumb (Cauvain and Young 2008).

In practical doughmaking and dough handling the distinction between one physical property and another is often hard to make because of the interaction of the dough with processing methods, such as moulding, as will be discussed in Chap. 4. During processing the dough is subjected to different magnitudes of force and those forces are applied at different rates. At the same time the dough is subject to physical change as a result of chemical actions at the molecular level, along with further effects from the physical forces associated with gas production.

We can therefore see dough development as being the modification of some very important physical properties of bread doughs which make major contributions to the character of the final product. This modification of gluten structure can be achieved by a number of different physical and chemical processes, and various combinations of these form the basis of the different groups of breadmaking processes which are in common use.

Most of the desirable changes resulting from ‘optimum’ dough development, whatever the breadmaking process, are related to the ability of the dough to retain gas bubbles (air) and permit the uniform expansion of the dough piece under the influence of carbon dioxide gas from yeast fermentation during proof and the early stages of baking. The creation of dough with a more extensible character is especially important for improved gas retention, while reductions in dough resistance and elasticity play a major role in the modification of bubble structures during processing, as will be discussed in more detail for some of the breadmaking process groups described below.

It is important to distinguish between gas production and gas retention in fermented doughs. Gas production refers to the generation of carbon dioxide gas as a natural consequence of yeast fermentation. Provided the yeast cells in the dough remain viable (alive) and sufficient substrate (food) for the yeast is available, then gas production will continue, but expansion of the dough can only occur if that carbon dioxide gas is retained in the dough. Not all of the gas generated during processing, proof and baking will be retained within the dough before it finally sets in the oven. The proportion that will be retained depends on the development of a suitable gluten matrix within which the expanding gas can be held. Gas retention in dough is therefore closely linked with the degree of dough development which occurs, and as such will be affected by a large number of ingredients and processing parameters which are not necessarily independent of one another.

A further distinction should be made between dough development and gas retention and the factors which affect both. Dough development is a poorly-defined term used by bakers to indicate when they believe that the dough has all of the necessary physico-chemical properties it needs to deliver the required bread characteristics. This precise combination of properties varies with the breadmaking method employed, the equipment and the product type but is essentially based on the development and modification of the gluten network in the dough. Since gluten is the essential ‘ingredient’ in achieving the required dough development it follows that flour is the primary ‘building block’ in that process. Improved dough development leads to improved gas retention which is manifest through increased bread volume, crumb softness and changes in crumb structure and texture.

The ingredient and process interactions which affect the formation of the gluten network in the dough will be discussed in detail in the following sections and chapters. It is recognised that the addition of many ingredients will impact on the gas retention properties of the dough and lead to increased product volume (and softness). However, not all of the additions which improve dough gas retention impact on product cell structure and this is because some of them do not make a direct contribution to dough development. Studies by Miller et al. (2005) of dough mixing using near infrared (NIR) technologies have shown no changes in NIR 'optimum' mixing (dough development) time with changing levels of ingredients such as emulsifiers and enzymes. The precise relationship between dough development and gas retention is not clear but it is clearly wrong to assume that all improvements in gas retention are the direct result of improvements in dough development.

Cell Creation and Control

The production of a defined cellular structure in the baked bread depends entirely on the creation and retention of gas bubbles in the dough. After mixing has been completed, the only 'new' gas which becomes available is the carbon dioxide gas generated by the yeast fermentation. Carbon dioxide gas has many special properties and at this point we are concerned with two: its high solubility by comparison with the other major gases in breadmaking, nitrogen and oxygen and its relative inability to form gas bubbles in dough. As the yeast produces carbon dioxide gas, the latter goes into solution in the aqueous phase within the dough. Eventually the solution becomes saturated and unable to hold any further carbon dioxide which may be produced. The rate at which saturation occurs depends on the fermentation conditions, but is fairly fast in all breadmaking processes, as shown by rapid dough expansion as the gas is retained within the developing or developed dough structure.

If the carbon dioxide does not form its own gas bubbles how then does expansion of the dough through gas retention occur? Two other gases are available in significant quantities within the dough as a result of mixing, oxygen and nitrogen, both of which are derived from any quantities of air trapped within the dough matrix as it forms. In the case of oxygen, its residence time within the dough is relatively short since it is quickly used up by the yeast cells within the dough (Chamberlain 1979; Chamberlain and Collins 1979). Indeed so successful is yeast at scavenging oxygen that in some breadmaking processes no oxygen remains in the dough by the end of the mixing cycle. The rapid loss of oxygen from mechanically developed doughs has been illustrated previously for a wide range of nitrogen to oxygen ratios (Collins 1985).

With the removal of oxygen from the dough, the only gas which remains entrapped is nitrogen and this plays a major role by providing bubble nuclei into which the carbon dioxide gas can diffuse as the latter comes out of solution. The number and sizes of gas bubbles available in the dough at the end of mixing will be strongly influenced by the mechanism of dough formations the mixing conditions in a particular machine and its design. The influence of mixing action in each of the breadmaking processes will be further discussed below and the effects of mixer design in Chap. 4. At this stage it is only necessary to register the significant role that mixing will play in the creation of dough bubble structures for subsequent expansion.

It is now clear that for most breadmaking processes, particularly those which do not include a bulk dough resting time, the finest cell structure we can form is already in the dough by the end of the mixing process (Cauvain and Collins 1995). During the processing stages subsequent to mixing some modification of the bubble structure does occur which essentially comprises an expansion of the bubbles already created (Whitworth and Alava 1999). The modification of bubble structures in the dough after mixing depends to a significant extent on the rheological qualities of the dough and we will be concerned with three of the rheological properties described earlier.

Major Breadmaking Process Groups

The sequences required for a complete breadmaking process have been briefly described above. The processing stages which occur after dividing the bulk of the dough, such as shaping, proving and baking, are largely common to all breadmaking processes, and so when we discuss the different breadmaking processes we are mainly concerned with the methods which are used to produce the developed bulk dough ready for dividing and further processing. In discussing the different processing methodologies we will also recognize the important contribution that different ingredient qualities and formulations play in determining dough development within a particular breadmaking process.

The methods by which dough development is achieved in the bakery may be fitted into four broad processing groups, although there are numerous variations and also elements of overlap between each of the individual groups. For discussion purposes we can name and characterize the groups as follows:

- *Straight dough bulk fermentation*, where resting periods (floor-time) for the dough in bulk after mixing and before dividing are the norm. For the purposes of discussion in this chapter, a minimum bulk resting period of 1 h will be required for a process to fit into this category.
- *Sponge and dough*, where a part of the dough formulation receives a prolonged fermentation period before being added back to the remainder of the ingredients for further mixing to form the final dough, which is then commonly processed without further delay.
- *Rapid processing*, where either a very short (<1 h) or no period of bulk fermentation is given to the dough after mixing and before dividing.
- *Mechanical dough development*, where a primary function of mixing is to impart significant and often measured quantities of energy to facilitate dough development, and the dough moves without delay from mixer to divider for further processing.

Delayed addition of salt. While strictly not a defined breadmaking process because it could be used with any of the four processes described above, some bakers may delay the addition of salt until the later stages of mixing. The objective is to permit full hydration of the proteins in the flour and the optimisation of the gluten structure in the dough before the water-binding effects of salt (sodium chloride) are introduced. The salt is readily soluble in the dough and quickly disperses. However, the technique is most applicable to low speed mixing and with mixers which allow ready access to the dough during processing. Dosing salt late in short-time, high speed mixing processes (e.g. Mechanical Dough Development) present practical problems though technically it could be arranged. The lack of inhibiting effect on the yeast by delaying salt addition is not commonly a problem because the delayed salt method is most commonly employed in breadmaking processes where the dough is rested after mixing and before dividing. The dough may have slightly more gas present by the end of the resting period but the impact will be small.

Each of the process groups identified above has a similar equipment requirement in that they all need some means of mixing the ingredients together to form a cohesive dough. The nature of that mixing equipment will make an important contribution to dough development and so it is inevitable that in discussing the individual groups some consideration has to be given to the type of equipment used. To some extent, individual breadmaking processes have become synonymous with different mixers but in many cases that relationship is not absolute since several different mixer types may be capable of exploiting the principles of the same breadmaking process. The suitability of different mixers is most limited in the case of mechanical dough development processes where high mixing speeds and control of the atmosphere during the mixing cycle become very important in achieving the desired bread character (Cauvain and Young 2006).

In commercial practice a close link has also developed between the type of breadmaking process and the scale of manufacture. Once again this link is not absolute with any of the breadmaking process groups being capable of exploitation by bakers of any size. Some breadmaking processes are more sensitive than others to variations in processing conditions, such as time and temperature, and consequently there has been a tendency in smaller-scale bakeries, where greater process flexibility is required, to use the more tolerant and less process sensitive of the breadmaking processes.

Polarization of products to different breadmaking methods has also tended to occur, in part because of the choices of equipment made by bakers, especially at the smaller end of the production scale. In seeking to use breadmaking methods in combination with equipment which give increased flexibility and ‘tolerance’ during processing some bakers have limited their options with regard to the range of bread qualities which it is possible for them to make. At the other end of the scale plant production has also tended to limit its options, although in this case it is because bakers have sought efficiencies of scale and close process control. In some cases, limited appreciation of the critical factors which affect bread quality for a particular process has resulted in particular bread types which have become synonymous with particular breadmaking processes. It is certainly true that not all of the breadmaking processes are equally capable of making optimum quality-bread over the full range of bread types we encounter, but often the possible range of qualities is greater than is appreciated or indeed exploited for any particular process.

It is a mute question as to whether the qualities of the flours which are available determine the breadmaking process to be used or whether the process to be used determines the flour qualities required. In fact, whichever way we answer the question we are correct. As breadmaking processes developed around the world, the ‘strength’ of the locally available flour had to be accommodated, but as our knowledge of the breadmaking process has increased we have come to learn that there are many different ways of achieving a particular bread quality, and in doing so we have learned that flour quality can be adjusted to achieve our desired aims. In modern breadmaking it is certainly true that the ‘best’ (usually taken to mean the strongest, the highest protein quantity or quality) wheats will make the ‘best’ flour for a given process. As we shall see, factors such as bread volume will increase with increasing protein content, but the price we may have to pay with such stronger flours is the adjustment of our preferred processing method. In some cases where we have a fixed processing method, we may not be able to accommodate ‘improvements’ in flour quality. This close relationship between flour properties and processing methods will be expanded upon in discussion of the individual processing method groups which follows.

Straight Dough Bulk Fermentation

For many, the application of bulk fermentation for dough development is probably the most traditional and most ‘natural’ of the breadmaking processes. This process group is the most homogenous of all the groups we shall be discussing since the variations within it tend to be confined to different periods of bulk fermentation time, with variations in some other aspects of controlling fermentation, such as those associated with temperature or yeast level. There are only a few essential features of bulk fermentation processes and can be summed up as follows:

- mixing of the ingredients to form an homogeneous dough;
- resting of the dough so formed in bulk for a prescribed time (floor-time), depending on flour quality, yeast level, dough temperature and the bread variety being produced;
- part-way through the prescribed bulk fermentation period there may be a remixing of the dough (a ‘knock-back’ or ‘punching down’).

Dough formation for bulk fermentation is usually a low-speed affair carried out by hand or with low-speed mixing machines. Whether mixed by hand or by machine, the amount of energy which is imparted to the dough is very small by comparison with that experienced in other types of breadmaking processes. This is an important distinction because it shows that dough development is almost completely limited to that achieved in the fermentation period. This being the case, control of the factors which affect the bulk fermentation period and the quality of the ingredients used is especially important for optimum bread quality. The formulations for bulk fermentation need only contain a few ingredients as shown in Table 2.1.

Table 2.1 Recipes for bulk fermented doughs

	3 h (%)	1 h (%)
Flour	100	100
Yeast	1	2
Salt	2	2
Water	57	58

Yeast Level

The differences in yeast levels in the two examples of recipes given in Table 2.1 occur because more yeast is required with shorter bulk fermentation periods in order to achieve full dough development in the shorter time. This relationship between dough development time and yeast level probably comes from the contribution that enzymes present in the yeast cells, viable or dead, make to modification of the protein structures which are forming with increasing dough resting time. Of the enzymes present, the proteolytic enzymes and the natural reducing agent glutathione are likely to play the major roles. Flour too contains enzymes which can contribute to dough development.

If we take this relationship between yeast and bulk resting time to its ultimate conclusion we could continue to increase the yeast level and expect to eliminate bulk time altogether. Indeed it is possible to make a ‘no-time’ dough in this manner, but the resulting bread will be somewhat poorer in quality than we might expect from 1 or more hours of bulk time. This no-time doughmaking approach has been used by bakers and is often referred to as an ‘emergency dough’ to be made when there is insufficient time available to allow for a bulk rest of the dough (Ford 1975). We can see then that while there is a working relationship between yeast level and bulk time the passage of a period of time is still very important for gluten modification and the production of suitable bread quality to occur, whatever the level of yeast added. For practical purposes a period of at least 1 h in bulk should be given to the dough.

Since the mechanism for dough development in bulk fermentation depends to a significant degree on yeast activity, we can also reasonably expect dough temperature to play a major role in determining the time at which full development is achieved for a recipe with a given yeast level. This is certainly the case and in bulk-fermented doughs it is normal to adjust the yeast level, or bulk time, or both, with changes in dough temperature, whether the latter is deliberately introduced or occurs from some unintentional source. There are no ‘hard or fast’ rules for temperatures in the bulk dough at the end of mixing, but conventional practice places final dough temperatures in the region of 21–27 °C (70–80 °F). As a ‘rule of thumb’ a 4 °C rise in dough temperature can be offset by a reduction in yeast level by one-half. Conversely a 4 °C fall in dough temperature requires a doubling in added yeast. The practising baker will be familiar with such relationships and may make appropriate adjustments with rises and falls in ambient bakery temperatures in those countries which experience significant changes in daily and seasonal temperatures. In the context of dough temperature control Calvel et al. (2001) considered that the control of the final dough temperature was one of the most significant factors in achieving consistent bread quality using fermentation systems.

Flours

The 'strength' of the flour which can be used in bulk-fermented doughs is closely linked with the length of the bulk fermentation period which we employ. In general, the stronger the flour, the longer the fermentation period we will require in order to achieve optimum dough development (Fig. 2.3), and the better the final bread quality will be (i.e. with a larger volume, finer crumb structure and softer crumb). Flour strength is largely related to its protein content and quality, as will be discussed in Chap. 12, so that higher protein flours require longer bulk fermentation times than lower protein flours to deliver optimum bread quality. The level to which bran is present in the flour will also affect the length of bulk fermentation times, with wholemeal (wholewheat) flours requiring shorter bulk time than white flours. A typical white flour protein content for bulk fermentation would be 12 % (14 % moisture) or greater.

Failure to match flour and bulk times will result in a number of quality defects in both the dough and the baked product. In the dough insufficient bulk time gives one which is 'under-fermented' or 'green'/unripe and will exhibit a tough, rubbery gluten, not easily given to being moulded and which, in turn, will yield loaves of small volume, dense cell structure and firm crumb. Too long a bulk time will result in the dough becoming 'over-fermented', readily giving up its gas at the slightest touch

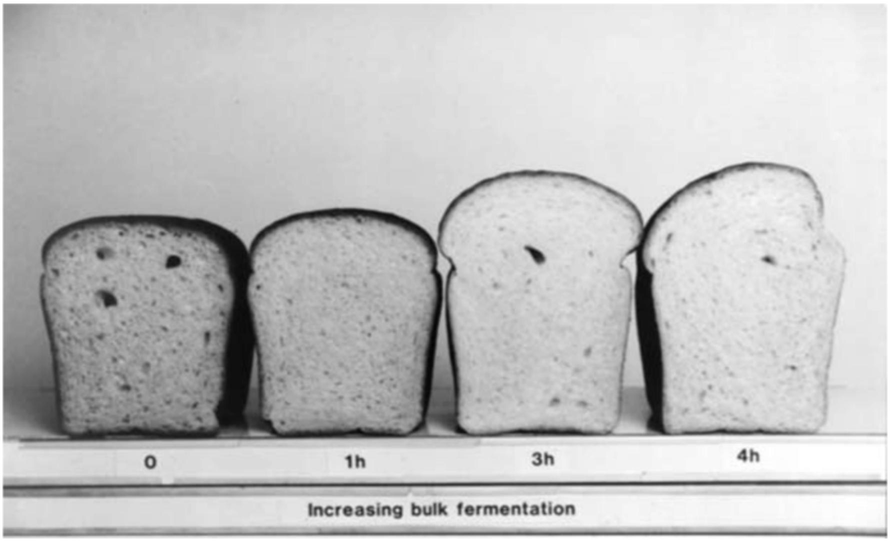

Fig. 2.3 Effect of bulk fermentation time on bread quality

and liable to collapse under its own weight. If bread be made from such a dough it is likely to have a poor shape, although with adequate volume, and an irregular cell structure, frequently with large holes. In part, these changes occur because there is a progressive change in the physical properties in the gluten in the dough. Commonly referred to as ‘relaxation’, the changes are usually a loss of resistance to deformation and elasticity which is accompanied by an increase in extensibility.

The supplementation of flours with dried, vital wheat gluten to raise the protein content of weaker base flours is a common practice in many parts of the world (Chamberlain 1984; Cauvain 2003). While such an approach works well in some breadmaking processes, gluten supplementation is less successful where mixing methods are of the lower speed, less intense form. This is sometimes the case in the production of bulk-fermented doughs and, even though a long resting period is available, the conditions are not suited to continuing gluten development. Some additional gluten development may be gained during remixing at knock-back but generally flours with higher levels of gluten supplementation do not perform as well as flours which contain the same level of indigenous protein.

Flours to be used for bulk fermentation processes are usually low in cereal *alpha-amylase* (high Falling Number) and will only be supplemented with low levels of fungal *alpha*-amylase or malt flour, if at all, because of the potential softening effects on the dough handling character with extended bulk resting time.

Water Levels

One of the most obvious manifestations of the changes taking place when the dough ferments in bulk is a progressive softening of the dough with increasing time. In breadmaking, bakers aim to achieve a ‘standard’ dough consistency for dividing and moulding. They accomplish this by adjusting the water level added during dough mixing according to the water absorption capacity of the flour (Chap. 12). During bulk fermentation progressive enzymic action is responsible for the softening of the dough which occurs. Since enzymic actions are time and temperature dependent, we can reasonably expect that dough softening will vary according to the bulk fermentation conditions, and in these circumstances adjustment of added water levels will have to be made to compensate for these changes. The recipes given in Table 2.1 show how a reduction in added water is required with longer bulk fermentation times in order to maintain a standard dough consistency for dividing.

Optional Ingredients

While the only essential ingredients required are those given in Table 2.1, other ingredients are sometimes added for making bread by bulk fermentation. Typical rates of addition for these optional ingredients and the properties they confer to the

Table 2.2 Optional ingredients in bulk fermentation

	Percentage of flour weight	Improvement
Fat	1.0–2.0	Gas retention
		Crumb softness
Emulsifiers	0.1–0.3	Gas retention
		Crumb softness
Enzyme-active malt flour	0.1–0.2	Gas production
		Gas retention
		Crust colour
Enzyme-active soya flour	0.2–0.5	Crumb whiteness
Skimmed milk powders	Up to 2.0	Crust colour
		Flavour

dough and the bread are given in Table 2.2. In addition to those optional ingredients identified in Table 2.2, 'improvers' may be added to bulk-fermented doughs. Usually the levels of addition are much lower than would be seen in no-time doughmaking processes. In some cases the 'improver' may consist of a small quantity of an oxidizing material added at the flour mill in order to assist in dough development (Chaps. 3 and 12). Various flour treatment agents are permitted for use around the world, although the numbers are becoming fewer. Supplementation with enzymes may also occur.

Process Variations

Reference has already been made to one process variation which may be encountered in bulk fermentation processes, namely the operation of 'knocking-back', 'punching down' or remixing the dough part way through the fermentation time. This operation tends to happen with doughs which are undergoing longer fermentation periods, greater than 1 h. A number of advantages are claimed for the operation, including equilibration of dough temperatures throughout its bulk and the incorporation of more air into the dough to improve yeast activity.

Other variations include the delaying of the addition of salt and yeast to the latter stages of mixing or, indeed, the later stages of bulk fermentation. Delaying the addition of these ingredients changes the manner and degree of the dough development process. For example, delaying the addition of salt until about two-thirds of the way through the bulk period increases the effects of fermentation without having to increase the bulk fermentation period. One of the common claims for delaying the addition of such ingredients is for the modification of flavours in the dough (Calvel 2001). The development of bread flavour has already been discussed in Chap. 1.

Creation of Bubble Structure

The basic elements of bubble structure creation have been described earlier in this chapter. As with all breadmaking processes, the gas bubbles in the dough at the end of mixing exhibit a range of sizes from a few µm to several mm. During the bulk fermentation period the evolution of carbon dioxide gas leads to the expansion of many of these bubbles. At the same time that the bubbles are being expanded, changes in the dough rheology are occurring which make it less resistant to deformation. Because of such changes it is possible to collapse many of the larger bubbles in the dough during the knock-back or moulding stages which leaves the many smaller bubbles which are subsequently inflated by more carbon dioxide gas. Baker and Mize (1941) showed this to be the case for bulk-fermented doughs and considered that such events were major contributors to the formation of fine and uniform cell structure in bread made from bulk-fermented doughs. In the past, when bulk fermentation was the norm, craft bakers advocated the modification of bread cell structure using this principle of inflation, collapse, creation (more likely retention) of small bubbles and re-inflation for the production of so-called ‘competition breads’ with a finer and more uniform cell structure (Horspool and Geary 1985). Often the technique required that dough pieces be passed back and forth through the sheeting rolls of a pastry brake. Thus the creation of bread cell structures from bulk-fermented doughs clearly owes much to the manipulation of the dough during processing. This is not the case with no-time doughmaking processes as will be discussed below and in later chapters.

Sponge and Dough

Elements of sponge and dough processes are similar to those for bulk fermentation in that a prolonged period of fermentation is required to effect physical and chemical changes in the dough. In sponge and dough this is achieved by the thorough fermentation of part of the ingredients rather than all of them. The length of sponge fermentation times may vary considerably, as may the composition of the sponge. In some cases the sponge component may be replaced with a flour brew in which the proportion of liquid is much higher than that used in a sponge.

The key features of sponge and dough processes are:

- a two-stage process in which part of the total quantity of flour, water and other ingredients from the formulation are mixed to form an homogeneous soft dough—the sponge;
- resting of the sponge so formed, in bulk for a prescribed time (floor-time) and under defined temperature conditions, mainly depending on flavour requirements;
- mixing of the sponge with the remainder of the ingredients to form an homogenous dough;
- immediate processing of the final dough, although a short period of bulk fermentation period may be given.

In the UK, sponge and dough formation tends to be a low-speed process carried out with low-speed mixing machines, while in North America more intense mixing is given to the sponge and the subsequent dough. On a small scale the mixer used to form the sponge may also provide the container in which to store it, provided it is not required for other uses. In large-scale production of sponges, separate containers which can be moved to temperature-controlled environments are needed in order to ensure uniformity of sponge development and to achieve the required scales of manufacture.

Roles of the Sponge

The main roles of the sponge are to modify the flavour and to contribute to the development of the final dough through the modification of its rheological properties. The process of flavour development in the sponge, though complex, is manifested in a relatively straightforward manner with an increase in the acidic flavour notes arising from the fermentation by the added yeast and other microorganisms naturally present in the flour (usually lactic acid bacteria). To maintain the right flavour profile in the finished product, the sponge fermentation conditions should be closely controlled and care should be taken to avoid a build-up of unwanted flavours by thorough cleaning of storage containers after use.

During the sponge fermentation period there will be a decided decrease in sponge pH with increasing fermentation (whether arising from changes in time, temperature, or both). It should be noted that the degree to which sponge pH can be lowered may well be affected by the source of the wheat flour. This is especially the case in countries like the UK where the mandatory addition of chalk to the flour in the mill limits the drop in the pH because of the buffering effect of calcium carbonate. The rheological character of the gluten formed during the initial sponge mixing will change, with the sponge becoming very soft and losing much of its elasticity. As standing time increases the condition of the sponge increasingly resembles an over-fermented dough. The low pH of the sponge and its unique rheological character are carried through to the dough where they have the effect of producing a softer and more extensible gluten network after the second mixing. In many cases the addition of the sponge changes the rheological character of the final dough sufficiently to render further bulk resting time unnecessary, so that dividing and moulding can proceed without further delay.

Formulations

The main requirement for sponge and dough processes is to decide what proportion of the total flour is to be used in the production of the sponge. This proportion will vary according to individual taste and location. Two examples are given in Table 2.3,

Table 2.3 Examples of sponge and dough formulations (ingredient proportions expressed as percentage total flour weight)

	Sponge	Dough
UK 16 h sponge		
Flour	25.0	75.0
Yeast	0.18	1.75
Salt	0.25	1.75
Water	14.0	43.0
Fat	0.0	1.0
North American 4 h sponge		
Flour	65.0	35.0
Yeast	2.4	0.0
Salt	0.0	2.3
Water	40.0	25.0
Improver	0.1	0.0
Milk solids	0.0	3.0
Sugar	0.0	6.0
Fat	0.0	3.0

one for a typical 16 h (overnight) sponge in the UK and the other a 4 h example from North America. The contrast in the approaches is very evident.

Improvers

Additions of improvers are not essential to the production of bread by sponge and dough methods since a contribution towards dough development is made directly by the sponge. However, as shown by the example of a North American recipe in Table 2.3, improver additions are common in some variations of the process. The choice of improver type and the timing of the addition, whether to the sponge or the dough, depend to a large extent on the bread variant being produced and traditional practices.

There will be different potential effects from the different oxidizing agents present if the improver is added to the sponge side of the process. Late-acting oxidizing agents have little or no effect until the dough reaches the prover (proofer) while faster-acting oxidizers, such as ascorbic acid and azodicarbonamide will act in the sponge mixing stage. In the case of ascorbic acid, oxygen is required for oxidation of the dough proteins to occur (Collins 1994). Within the sponge the atmosphere will quickly become anaerobic and so opportunities exist for the ascorbic acid in particular to act as a reducing agent, its true chemical form, and to modify (weaken) gluten structures. The opportunities for enzymic action from the improver should also be considered, so that all in all there is a strong case for restricting improver additions to the dough side of the process where control of the changes which may occur is more readily achievable.

Flours and Other Ingredients

Flours used in typical sponge and dough production will be at least as strong as those used in bulk-fermented doughs with protein contents not less than 12 % (14 % moisture). As with bulk-fermented doughs, flours for sponge and dough tend to have high Falling Numbers. High *alpha*-amylase activity could be a problem in the sponge, but is less likely to be a problem in the dough since the latter rarely has any floor-time after mixing.

Process Variations

The most obvious of process variations encountered with sponge and dough systems will be variations in the sponge fermentation times. These will vary according to individual requirements for efficient processing, flavour development and available raw materials. Sponge temperatures will vary but are usually kept to maximum of 21 °C (70 °F). Final dough temperatures will fall into a similar range to those used in bulk fermentation, between 21 and 27 °C (70–80 °F).

In some cases the sponge may be incorporated into a dough which is then given a period of bulk fermentation or it may be added to doughs which are to be developed by a rapid processing method or by the Chorleywood Breadmaking Process (CBP), as will be discussed below. Since a primary function of a sponge is to develop bread flavour, alternative liquid brew or ferment systems have developed to fulfill this function. In most cases there will be little or no dough development function from the brew, other than that which comes from the ingredients. The application of liquid brews to the production of hamburger buns is described in Chap. 9.

Rapid Processing

This heading covers a multitude of slightly different breadmaking systems, each of which has evolved based on different combinations of active ingredients and processing methods. A common element to all breadmaking processes covered under this heading will be the inclusion of improvers 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. Processes which are covered by this heading include activated dough development, no-time doughs with spiral mixers and the Dutch green dough process.

Activated Dough Development (ADD)

This process was developed in the USA during the early 1960s (Brown 1993) and became popular in smaller bakeries in the USA and the UK thereafter. Its essential features were:

- the addition of a reducing agent, usually; L-cysteine hydrochloride
- the addition of oxidizing agents;
- the addition of a fat or an emulsifier;
- extra water in the dough to compensate for the lack of natural softening;
- extra yeast to maintain normal proving times.

Since its first introduction ADD has undergone a number of changes and now seldom exists in its ‘classic’ form. When ADD was first introduced, potassium bromate was a common component in the added improver, together with ascorbic acid and L-cysteine hydrochloride. The increasing expense of L-cysteine hydrochloride and the withdrawal of potassium bromate from many permitted lists of breadmaking ingredients have both played a role in the demise of ADD certainly in the UK and elsewhere.

Since the dough development process in ADD was mostly chemically induced, low-speed mixers could be employed. This allowed craft bakers to continue using their existing low-speed mixers and eliminate bulk fermentation without purchasing high-speed mixers being developed for mechanical dough development processes in the 1950s and 1960s. With the passage of time many of the smaller bakers changed to spiral-type mixers which allowed them to move to improver formulations with fewer ‘chemicals’ at a time when consumer attitudes to ‘additives’ were changing.

A short period of bulk fermentation (typically less than 30 min) before dividing was beneficial for ADD product quality. Sponges could be added to change bread flavour if required. Final dough temperatures were in the region of 25–27 °C (76–80 °F).

No-Time Dough with Spiral Mixers

In many bakeries, especially the smaller ones, the spiral mixer has taken over as the main type of mixer being used. Spiral mixers have a number of advantages for no-time doughmaking processes in smaller bakeries or where fine cell structures are not required in the baked product. These will be discussed in more detail in Chap. 4 but it is worth noting at this stage the input of higher work levels than those used with traditional low-speed mixers, with accompanying reductions of mixing times to achieve optimum dough development.

Although mainly used for no-time doughs some bakers will use short periods of bulk fermentation, usually 20–30 min, to assist with dough development after mixing. In these circumstances the control of final dough temperature is important in order to both control and optimize dough development. The additional gas generated during such bulk resting periods will place greater demands on divider weight control and yield products with a more open cell structure. Flavour development in the crumb is likely to be limited given the short time periods which are commonly used.

Some spiral mixers impart sufficient energy to raise dough temperatures above that expected from the ingredients. Final dough temperatures vary widely for no-time doughs with spiral mixers, and practical examples may be found from 21 °C (or lower e.g. for frozen doughs), to 27 °C (70–80 °F). For many bakers the advantage of using lower dough temperatures lies in restricting yeast activity which comes with the usually higher levels of added yeast. A counter to this advantage is the reduction in chemical and enzymic activity which will occur at lower dough temperatures with a subsequent reduction in overall dough development.

The Dutch Green Dough Process

This process was developed in the Netherlands, hence its name. It is included under this process group heading since the mixed dough passes without delay to dividing, although significant periods of resting are involved in the total process. The essential features of the process are:

- mixing in a spiral-type mixer or extra mixing in a speeded-up conventional low-speed mixer;
- the dough is divided immediately after mixing;
- the divided dough is rounded and given a resting period of the order of 35–40 min;
- the dough is re-rounded and given a further resting period before final moulding.

The basis of the name ‘green’ refers to the fact that after the mixing the dough is considered to be underdeveloped or ‘green’ in classic bakery parlance. Dough development continues in the resting periods after each rounding. When first introduced, two or three resting periods were used; now it is more common to see one or, to a lesser extent, two.

Role of Improvers and Other Ingredients in Rapid Processing

Although it is possible to make no-time doughs without additional ingredients, such as with the traditional Dutch green dough process, it is common for improvers to be added to assist with dough development in the absence of bulk fermentation time.

The compositions of improvers which are used vary widely, although the most common ingredients are ascorbic acid, enzyme-active materials and emulsifiers. The degree of oxidation gained from the ascorbic acid depends in part on the level used and in part on the mixing machine and its ability to occlude air during the mixing operation. This latter aspect is discussed in more detail in Chap. 4.

Most no-time dough processes use flours of the stronger type with protein contents of 12 % (14 % moisture basis) or more. Since there is no appreciable softening of the dough from fermentation before dividing, water additions will be higher than in bulk fermentation. The precise water level used will also be influenced by the type of mixer, with some doughs being softer and stickier when taken out of one machine compared with another. Often this initial stickiness is lost in the first few minutes after leaving the machine. The cause of this phenomenon is not clear but may well involve the quantity of gas remaining in the dough at the end of mixing (see below).

Mechanical Dough Development

The common elements of this group are that there is no fermentation period in bulk and dough development is largely, if not entirely, achieved in the mixing machine. In mechanical dough development the changes brought about by bulk fermentation periods are achieved in the mixer through the addition of improvers, extra water and a significant planned level of mechanical energy.

The principle of mechanical dough development were exploited in the 1950s by the Wallace and Tiernan ‘Do-maker’ (Williams 1975). The loaf coming from the ‘Do-maker’ had a characteristically fine and uniform cell structure which eventually proved to be unpopular with many consumers, and today few installations remain in use. The ‘Do-maker’ used a continuous mixer and separate developer chamber. Other processes which exploited the same principles of mechanical dough development and continuous mixing included the Henry Simon-Strahmann plant, the Amflow process and the Oakes Special Bread Process. Like the ‘Do-maker’, few installations remain in use though interest in the applications of continuous dough mixing has again increased in recent years (see Chap. 3).

In 1958 the British Baking Industries Research Association at Chorleywood, UK (later merged into the Flour Milling and Baking Research Association and more recently into the Campden & Chorleywood Food Research Association) began to investigate the important factors in the mechanical development of dough. The work was to lead to the one mechanical dough development process which has stood the test of time—the Chorleywood Breadmaking Process (CBP) (Cauvain and Young 2006)—and this process will serve as the basis for discussing and understanding the key issues in mechanical dough development. More detailed discussion of the CBP-compatible mixing equipment and its functions are contained in Chap. 4.

Chorleywood Bread Process (CBP)

The basic principles involved in the production of bread and fermented goods by the CBP remain the same as those first published by the Chorleywood team in 1961, although the practices have changed with changes in ingredients and mixing equipment (Cauvain and Young 2006). The essential features of the CBP are:

- mixing and dough development in a single operation lasting between 2 and 5 min at a fixed energy input;
- the addition of an oxidizing improver above that added in the flour mill;
- the inclusion of a high melting point fat, emulsifier or fat and emulsifier combination;
- the addition of extra water to adjust dough consistency to be comparable with that from bulk fermentation;
- the addition of extra yeast to maintain final proof times comparable with those obtained with bulk fermentation;
- the control of mixer headspace atmosphere to achieve given bread cell structures.

The main difference between the CBP and bulk fermentation processes lies in the rapid development of the dough in the mixer rather than through a prolonged resting period. The aim of both processes is to modify the protein structure in the dough to improve its ability to stretch and retain gas from yeast fermentation in the prover; in the case of the CBP this is achieved within 5 min of starting the mixing process. The advantages gained by changing from bulk fermentation to the CBP include:

- a reduction in processing time;
- space savings from the elimination of the bowl of dough at different stages of bulk fermentation;
- improved process control and reduced wastage in the event of plant break-downs;
- more consistent product quality;
- financial savings from higher dough yield through the addition of extra water and retention of flour solids which are normally fermented away.

Disadvantages include:

- faster working of the dough and greater process control are required because of the higher dough temperatures used;
- a second mixing will be required for the incorporation of fruit into fruited breads and buns;
- in some views, a reduction of bread crumb flavour because of the shorter processing times.

The last disadvantage listed is one of continual debate which has been constantly fuelled by the detractors of the CBP without any real understanding of the processes by which bread flavour is developed. The basis of bread crumb flavour development was discussed in Chap. 1, and while undoubtedly linked with the length of bulk fermentation time, in these days of predominantly no-time doughs, is probably more likely to be affected by ingredient additions and crust formation. If increased flavour is required in bread crumb made by the CBP, then the use of a sponge or a flour brew is recommended. Bulk fermentation after the completion of dough mixing in the CBP is not recommended because of the adverse changes which occur in the dough and the loss of subsequent bread quality.

Role of energy during mixing. The role that energy plays in optimizing bread quality during mechanical dough development can be readily assessed by comparing the loaves illustrated in Fig. 2.4. As the level of energy per kilogram of dough in the mixer increases, so bread volume increases, and with this comes a reduction in cell size and increased uniformity. With the range of flours studied when the CBP was first introduced into the UK, optimum energy levels quickly became standardized at 11 W-h/kg dough (5 W-h/lb) with little, if any, benefit being gained in varying from that level. Later work in New Zealand (Waters et al. 2013), the USA and the UK was to show that optimum work input varied according to flour characteristics with those derived from ‘extra strong’ wheats requiring optimum energy inputs above the standard 11 W h/kg. Despite the variation in total energy input, optimum bread quality with such flours in the UK was only gained by increasing the mixing speed in order to continue to deliver the energy within the specified 2–5 min time scale. An example of this relationship is illustrated in Fig. 2.5 for a UK wheat variety.

The role of energy during CBP mixing has yet to be fully explained. It is very likely that the high energy inputs are capable of mechanically breaking the disulphide bonds holding the original protein configurations together since such processes are known to occur in the mechanical modification of other molecules. The effect of mechanical energy might therefore be likened to the effects of natural or chemical reduction and, as such, will increase the sites available for oxidation. Chamberlain (1985) considered that only about 5 % of the available energy was required to break the disulphide bonds with the rest being consumed by mixing of the ingredients and the breaking of weaker hydrogen bonds. The mechanism of dough formation is discussed in more detail in Chap. 11.

The input of energy during mixing causes a considerable temperature rise to occur. Final dough temperatures are higher than those with other breadmaking processes and fall in the region of 27–32 °C (80–90 °F). Some bakers may see this as a

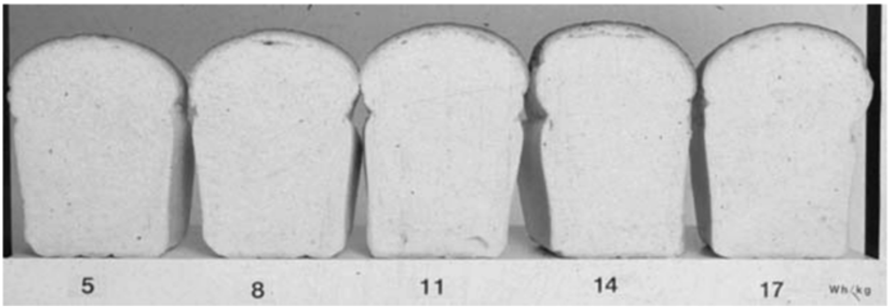

Fig. 2.4 Effect of energy input during mixing

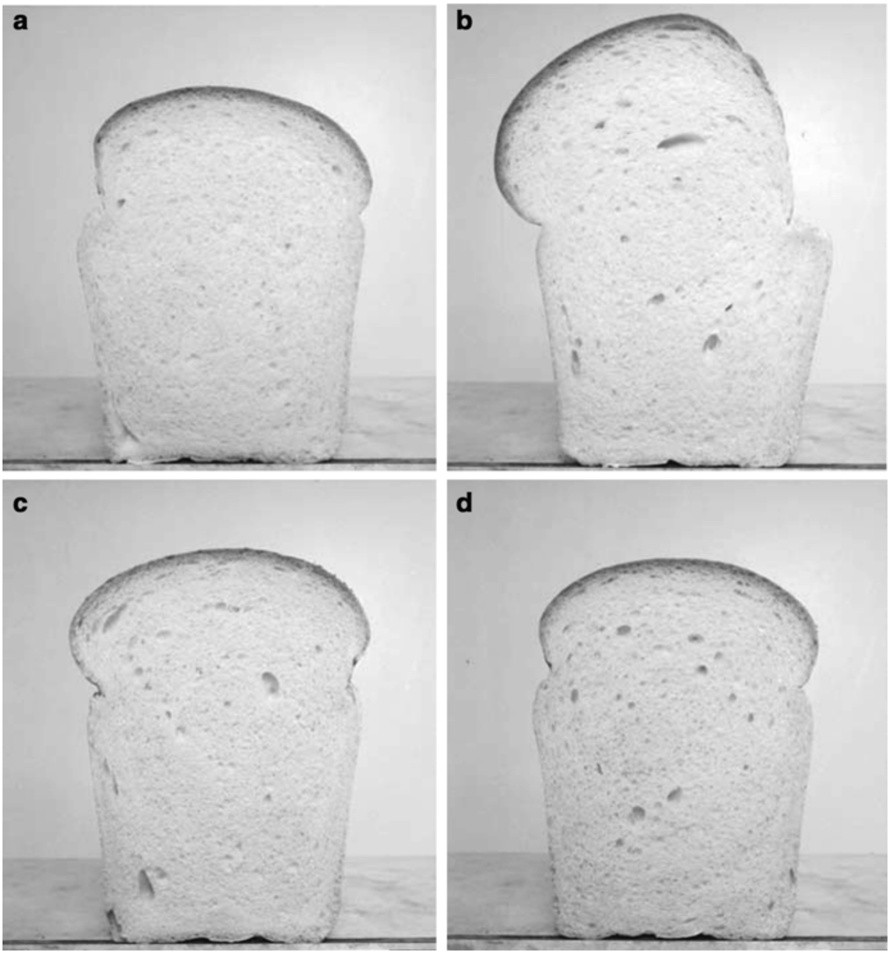

Fig. 2.5 Effect of energy input and mixing speed on bread quality. (**a**) 600 rpm and 5 W h/kg, (**b**) 600 rpm and 17 W h/kg, (**c**) 250 rpm and 5 W h/kg, (**d**) 250 rpm and 17 W h/kg

disadvantage in trying to control yeast activity, but the very short processing times which are used after mixing should not give rise to undue problems in a well-controlled bakery. As with no-time doughs from rapid-processing techniques, the small advantages gained by reducing yeast activity are outweighed by the loss of dough development. Further, the higher dough temperatures give a dough which is more ‘relaxed’ (has less resistance to deformation) during moulding and is less susceptible to moulder damage of the type which will be discussed in Chap. 4 and has been described elsewhere (Cauvain and Young 2008)

Energy and dough temperature control. The transfer of energy to the dough during mixing causes the final dough temperature to be considerably greater than would be expected from the simple prediction based on the knowledge of the temperatures and quantities of the ingredients used in the recipe. The control of dough temperature is vital if bread quality is to remain consistent.

The most common method for bakers to achieve a consistent final dough temperature is to adjust water temperature according to the temperature of the flour being used. The formula used is:

$$\text{T.water} = (2 \times \text{T.dough}) - \text{T.flour}$$

where the constant 2 is used because water has approximately twice the thermal capacity of flour and the level of added water is approximately half that of the flour weight, and T.dough is the dough temperature required at the end of mixing.

Thus if T.dough = 25 °C and T.flour = 20 °C then T.water = 30 °C.

This calculation works for hand and low-seed mixing and can be readily adjusted for changes in ambient bakery of equipment temperatures.

Mechanical mixing such as used in Mechanical Dough Development breadmaking or with spiral mixed doughs complicates the relationship because transfer of energy. The formula now becomes:

$$\text{T.water} = 2(\text{T.dough} - \text{T.rise}) - \text{T.flour}$$

where T.rise is the difference between the final dough temperature if the ingredients where simply blended together and the actual temperature achieved in the dough by the end of mixing.

T.rise can be calculated from a few simple experiments starting with ingredients of known temperatures and masses.

For example, in Mechanical Dough Development the energy transferred to the dough during mixing to 11 W h/kg resulted in the final dough temperature being 14 °C higher than predicted from the simple relationship and this value could be used could be substituted in the equation as follows:

$$\text{T.water} = 2(30 - 14) - 20$$

giving a required water temperature of 12 °C.

Because of the strong relationship between the temperature rise experienced by the ingredients in the dough formation process and the energy transferred during mixing it is possible to use the temperature data to ‘cross-check’ the energy balance during mixing. Such calculations are based on the specific heat capacities of the ingredients, their masses and temperatures, and the heat rise during mixing. For mixers running in a ‘steady’ state’, that is the mixer bowl is losing heat to the bakery atmosphere as quickly as it gains it during mixing, the impact of the metal of the mixer bowl is limited. Examples of the method for calculating energy inputs during mixing may be obtained from equipment manufacturers or published literature (e.g. Cauvain and Young 2006).

As mixing time or defined energy input changes then so will the temperature rise experienced by the dough. In practice it is advisable to carry out tests with a range of mixing conditions to cover the likely mixing scenarios. In some cases the temperature of the ingredients (particularly the flour) and the heat rise experienced during mixing are so significant as to require the use of ice. The latent heat required to convert ice to water is significant and has a powerful cooling effect on the dough. However, gluten development depends on the presence of water and so the use of large quantities of ice may restrict the initial hydration of the gluten-forming proteins. The implications of restricting hydration in the early stages of mixing dough by the CBP are not clear but pre-hydration of flour before intense mixing is often considered to be beneficial.

Flour quality. The process of mechanical dough development has been shown to make better use of the flour protein, and in the early stages of the development of the CBP it was quickly recognized that a given bread volume could be achieved with a lower flour protein content in the CBP than with bulk fermentation (Cauvain and Young 2006). This finding indicated that the protein content of flour could be reduced in some circumstances without the loss of key bread characteristics such as volume, crumb structure and crumb softness.

In the CBP, more than with many other breadmaking processes, there are no disadvantages in supplementing the flour with added dried vital wheat gluten. The move to lower protein contents and supplementation of indigenous protein with dried gluten were important factors in the ability of the UK milling industry to reduce the importation of high-protein North American wheats and to attain near self-sufficiency using home-grown or EC-grown wheats.

With mechanical dough development the quality characteristics demanded in the bread will largely dictate the flour specification and it is common for higher protein contents to be used for non-white bread varieties such as wholemeal (wholewheat) and mixed-grain breads where extra ‘support’ is required for the non-functional (in breadmaking terms) bran, grains and seeds (Fig. 2.6).

Creation of bubble structure. In contrast to the situation in bulk-fermented doughs the cell structure in the final bread does not become finer as the result of processing CBP doughs. In the case of CBP doughs, the final bread crumb cell structure is almost exclusively based on an expanded version of that created during the initial mixing process. The cell structure of UK sandwich breads made with dough taken straight from the mixer is contrasted with that which has been through the common processing sequence of rounding, resting and final moulding in Fig. 2.7. The loss of bread volume with the dough taken from the mixer can be attributed to the absence of intermediate proof during processing, an effect which will be discussed in Chap. 4. This illustration confirms work reported by Collins (1983).

The creation of bubble structures in mechanically developed doughs, and indeed for many other no-time processes, depends on the occlusion of air during mixing. The number, sizes and regularity of the gas bubbles depend in part on the mixing action, energy inputs and the control of atmospheric conditions in the mixer headspace. Collins (1983) illustrated how bread cell structure improved (in the sense of becoming finer and more uniform) with increasing energy input up to an optimum level with subsequent deterioration beyond that optimum. He also showed how

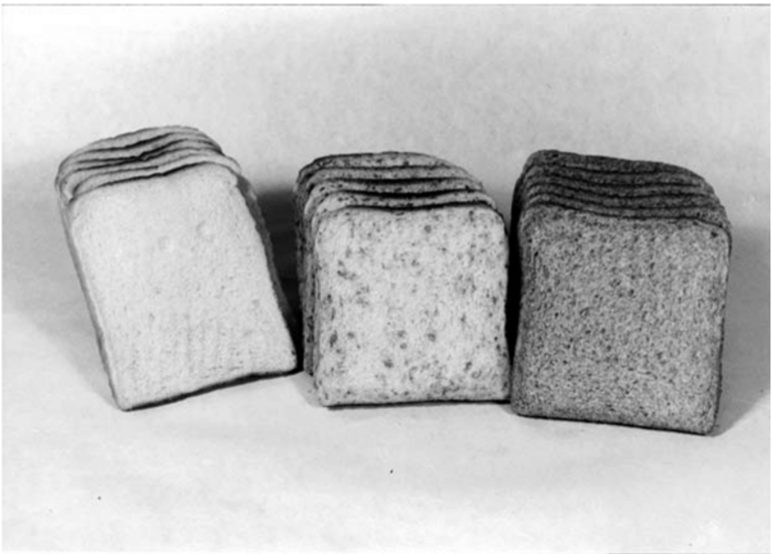

Fig. 2.6 *Left* to *right*, white, mixed grain and wholemeal breads made by the CBP

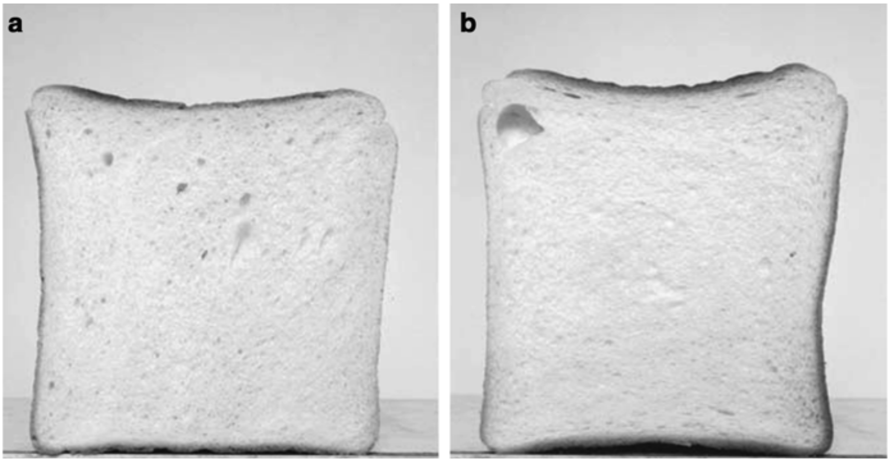

Fig. 2.7 Comparison of bread cell structures from dough (**a**) ex-mixer and (**b**) ex-final moulder

different mechanical mixing actions yielded breads with varying degrees of crumb cell size. Work to measure bubble distributions in CBP bread doughs (Cauvain et al. 1999) has confirmed that different mixing machines do yield different bubble sizes, numbers and distributions. However, in one CBP-compatible mixing machine, variation of impeller design had almost no effect on the bubble population. The lack of differences in the characteristics of the various dough bubble populations was confirmed by the absence of discernible differences in the subsequent bread cell structures.

The modification of bubble populations through the control of atmospheric conditions in the mixer headspace has been known for many years, commonly through the application of partial vacuum to CBP-compatible mixers (Pickles 1968). This control was useful in the creation of the fine and uniform cell structures typically required for UK sandwich breads, but was unsuited to the production of open cell structure breads. In the case of French baguette an open and more random cell structure could be created by extending the intermediate proof time to 20 or 30 min (Collins 1978), provided the delicate dough was given a gentle final moulding in order to preserve the large gas bubbles in the dough.

More recently developed, CBP-compatible mixers are able to work sequentially at pressures above and below atmospheric (Chap. 4). When the dough is mixed under pressure larger quantities of air are occluded, which gives improved ascorbic acid oxidation but more open cell structures. In contrast, crumb cell size becomes smaller as the pressure in the mixer headspace reduces and ascorbic acid oxidation decreases as the pressure decreases. The greater control of dough bubble populations realized in these mixers allows a wide range of bubble structures to be created in the dough. In addition to the fine and uniform structure created from the application of partial vacuum, an open cell structure for baguette and similar products can take place in the mixing bowl by mixing at above atmospheric pressure (Cauvain 1994, 1995). Doughs produced from this type of mixer retain their larger gas bubbles in the dough without significant damage during processing, even when intermediate proof times were shortened from 20 to 6 min.

Dough rheology. Some references have already been made to the importance of dough rheology in breadmaking and there is a detailed discussion of the interactions between the dough and its processing after mixing in Chap. 4. Comment has already been made on the fact that water levels have to be adjusted (upwards) in most no-time doughmaking methods in order to achieve the same dough consistency as would normally be achieved with doughs at the end of a bulk fermentation period. This required dough consistency largely arises because the original designs and functions of many dough processing plants were based on handling bulk-fermented doughs and were not suited to dealing with the firmer doughs yielded from no-time methods when the latter were introduced.

The requirement to add extra water to provide a softer, more machinable dough is particularly true when the doughs are mixed under partial vacuum in the CBP. The lower the pressure during mixing, the ‘drier’ the dough feels and the more water that needs to be added to achieve the same dough consistency as doughs at the end of a bulk fermentation period. This increased dryness with CBP doughs comes in part from the lower volume of gas occluded in the dough at the end of mixing (Chap. 4). If the dough is mixed at pressures greater than atmospheric then the quantity of gas occluded during mixing increases and doughs become softer for a given water level. Practical limitations to the application

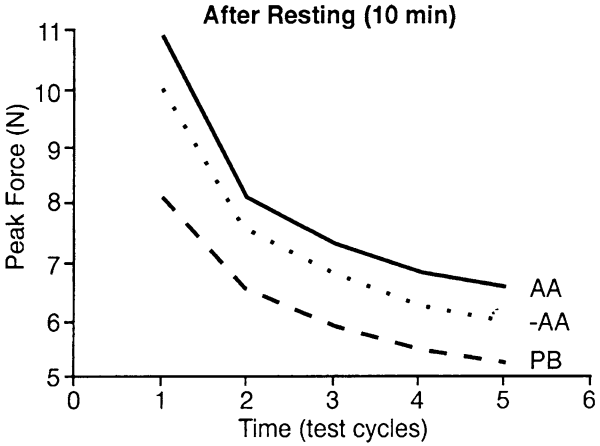

Fig. 2.8 Comparison of effects of ascorbic acid and potassium bromate on dough resistance to deformation (AA = with ascorbic acid, —AA = without oxidant, PB = with potassium bromate)

of partial vacuum are the reduction of the amount of oxygen available for ascorbic acid conversion and the need for some air to be occluded to provide gas bubble nuclei (Baker and Mize 1941). The degree to which mixer headspace can be lowered when mixing doughs in CBP-compatible mixers varies according to the machinery design and operational practices but commonly lies between 0.3 and 0.5 bar.[2]

The rheology of doughs from CBP-compatible mixers is also affected by changes in improver formulation, especially those related to dough oxidation. Cauvain et al. (1992) have shown that the resistance to deformation of CBP doughs was greater when ascorbic acid was compared with potassium bromate as the sole oxidizing agent (Fig. 2.8). This effect is most likely to be accounted for by the difference in the rate of action between these two oxidizing materials, with that for ascorbic acid taking place in the mixer and for potassium bromate mainly in the later stages of proof and thereafter. Other increases in resistance to deformation are observed when the oxidation from ascorbic acid is increased by modifying the mixer headspace atmosphere. Once again, a reduction in resistance (or perhaps more correctly a restoration to standard) may be affected by changing the levels of added water, although in commercial practice the addition of other ingredients in improvers, e.g. enzyme-active materials, may act to reduce dough resistance and increase dough stickiness (Fig. 2.8).

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[2] Confusion over pressure units can exist because of the way in which they are expressed. In part this arises because gauges fitted to mixers often express atmospheric pressure as being 0. A partial vacuum may be given as 0.5 bar vacuum and positive pressure may be given as 0.5 bar pressure. In this discussion atmospheric pressure is taken as being equal to 1 bar (or full vacuum = 0). Thus, a figure of 0.5 bar is 0.5 below atmospheric pressure, 0.3 bar is 0.7 bar below atmospheric, and 1.5 bar is 0.5 bar above atmospheric pressure.

Other Breadmaking Processes

Radical Bread Process

Interest in the manufacture of bread using less energy intensive processes while retaining the main elements of bread quality associated with Mechanical Dough Development led to the launching of the Radical Bread Process by Campden BRI, UK (Tucker 2011). The process is essentially a 'no-time' dough process in that the dough leaves the mixer and is processed without delay. However, unlike other doughmaking processes the bulk dough is not divided into unit pieces immediately after leaving the mixer, rather the bulk dough is transferred from the mixer and immediately processed by sheeting with unit pieces being cut and assembled from the sheeted and laminated dough some time after leaving the mixer.

The essential features of the Radical Bread Process were described by Miller and Tucker (2012) as:

- Combining the ingredients into an underdeveloped dough.
- Subjecting the dough to deformation shear by using lamination.
- Cutting the developed dough into pieces.
- Positioning the dough pieces in a pan so the laminations lie in one direction.
- Proving, baking and cooling as for pan bread.

The concept of an 'under-developed' dough was described mixing the dough long enough to achieve a homogeneous distribution of the ingredients and the complete hydration of the flour. As a result of limiting the time that the dough ingredients spend in the mixer there would be significantly less temperature rise (and lower energy consumption). The lower level of energy transferred to the dough by other means was the basis of the method. It was considered that many mixers could be used for preparing the dough though the development work was reported as being carried out with a high intensity Tweedy mixer. Dough development is considered to be achieved during the sheeting and laminating processes which follow mixing. In this respect the preparation of the dough is similar to that that referred to above for the preparation of competition breads based on a low intensity mixed dough, a resting period (bulk fermentation) and the modification of the dough with a pastry brake.

The creation of dough layers through the lamination process and cutting so that the alignment of the layers occurs in one direction are at the heart of the process. In one respect the elongation and re-alignment of gas bubbles in the dough piece are reminiscent of four piece moulding. Though in the case of the Radical Bread Process the impact may be greater because of delivery of more cells as disk-shaped ellipsoids. The end result is to create sandwich breads with more cells, less cell volume in the slice, and a brighter and softer crumb (Miller and Tucker 2012).

Sour Dough Processes

The manufacture of sour dough bread has a long history and is based on the spontaneous fermentation of flour through the symbiotic relationship between bacteria and wild yeasts. Variations in the microflora, fermentation conditions, types and ratios of raw materials are responsible for differences in the functionality of the sour and subsequent flavour in the bread. Sour dough technology is commonly based on wheat or rye flours, or a mixture of both. Such breads have distinctive acid flavours largely arising for the ratio of acetic to lactic acid flavour notes and the manufactured breads are denser with a less aerated structure than many other wheat breads.

The concepts of modern sour dough technology is still based on the preparation of a ‘starter’ or ‘mother’ dough to exploit the principles of spontaneous fermentation. Since the fermentation process cannot proceed without the presence of cereal starch as a food source for the microbial activity, it would eventually come to an end and so it is necessary to ‘top-up’ the food source with more flour (source of starch) in order to sustain the process. Each mother dough has its own unique starting culture of microorganisms which delivers its own special character and flavour profile in the finished bread. Bakers may choose to utilise specialist prepared sours which have been dried for supply to bakers who do not wish to manufacture and maintain their own starter.

The most common starter comprises only flour and water, replenished on a daily basis with new flour as required. The ratio of flour varies according to the preferences of the baker. The two most common forms of sour are those based on wheat and those based on rye. While their preparation is based on similar principles, the technical rationale behind their use is quite different. Some of the common sours may be described as follows:

- *Levain* based on spontaneous fermentation by ‘wild yeasts’ including *Saccharomyces* (S.) and *Candida* (*C.*) families, and the presence of *Lactobacilli* (*L.*). A variation is the *levain de pate* or pre-leavened dough where the addition of bakers’ yeast plays a role in the preparation of a ‘mixed’ sponge. The daily preparation of an acidic sponge is still required.
- The San Francisco sour dough associated with *L. sanfranciscensis* because it was in San Francisco, USA, that the microorganism concerned was first isolated and identified from dough. Usually a greater proportion of the total flour used in its preparation.
- The Poolish (Polish-style sponge) is a relatively liquid system comprising equal parts of flour and water. As its name suggests it was developed in Poland, probably sometime in the middle of the nineteenth century, and later adopted in Vienna and subsequently France (Calvel et al. 2001).
- The Biga which is a stiff commonly used in Italy with the addition of baker’s yeast. Typically it is fermented overnight (12–16 h).
- Rye bread sours (Schunemann and Treu 2001).

In the sour dough culture the symbiotic relationship between bacteria and yeast is important in sustaining fermentation. The bacteria ferment the more complex (larger molecular weight sugars) that the yeasts cannot use and fermentation is sustained because the yeast can metabolise the by-products of the bacterial fermentation (Cauvain in press). Each microorganism present in the microflora mix has a set of conditions in which it works best, with the major impact coming from the pH of the matrix and the temperature at which the sour is held. While the basic principle of the sour relies on symbiosis between bacteria and yeasts, there is also a competitive element to the relationship in that if storage conditions favour one organism more than another, the favoured organism may multiply to limit the potential of others.

After preparation and mixing of the bulk dough, it will be divided into unit pieces, shaped according to local preferences and then proved and baked. As noted above the final products tend to be denser than many other breads, often with a chewy texture. The mould-free shelf-life of sour dough breads tends to be longer than that of many wheaten bread products because of the lower pH and lower overall moisture content (water activity) the final product.

Breadmaking Processes, Bread Variety and Bread Quality

Each of the breadmaking processes discussed above has particular advantages and disadvantages and almost all types of bread and fermented goods can be made with each of them. There are, however, some combinations of breadmaking process and product type which are more successful than others, and because of this successful ‘partnership’ there has been a narrowing of views, a closing of minds and a limiting of the potential for all breadmaking processes. It was never the intention of this chapter to review in detail the advantages and disadvantages of each of the breadmaking processes though some references to such matters have been made where deemed appropriate. It will, however, be useful to conclude by considering how product requirements might influence the choice of breadmaking process.

Reference has already been made to the link in many minds between the fermentation process and bread flavour. All current breadmaking processes involve at least one fermentation period, namely the one bakers call proof. Whether sufficient bread flavours are achieved within that one relatively short process will be endlessly debated because, as commented on earlier, bread flavour is a personal issue. For those who require more flavour in their bread crumb, then the introduction of other fermentation stages is possible. With the introduction of a fermentation stage other than that required for proof come other factors which contribute to bread quality, the main one being an element of dough development, such as that seen in bulk development processes. Having chosen to make a ‘flavourful’ product then the baker must reconcile that requirement with a compatible breadmaking process. The choice of flavourful bread and no-time doughmaking process is not as incompatible as many would have us believe. There is absolutely no reason why we should not combine the benefits of better process control from no-time doughs with flavour, and several examples of using sponges to generate flavour before adding to no-time doughs have been discussed above.

Possibly more difficult to reconcile for the different breadmaking processes is the generation of the required cell structure for a particular product. Many bread products have distinctive crumb cell structures without which the product will simply not be authentic. The major difficulty lies not in making an open cell structure with a given breadmaking process since, as we have seen with the CBP this may simply be a case of using a longer first resting period (intermediate proof), but rather in the creation of the fine cell structures that are required for many breads. The strong link between the formation of an open cell structure and a crispy crust must be recognized, but again there is no reason why this should limit the breadmaking process chosen to achieve these given aims.

No-time doughmaking methods offer the best opportunity of achieving the finer cell structures since little expansion of the gas cells normally occurs until after the dough has been moulded. Provided we have achieved 'optimum' dough development and do not treat the dough harshly during processing, we should retain all the necessary dough qualities to guarantee a fine crumb cell structure. Of the no-time doughmaking methods which have been discussed, the contribution of energy in mechanical dough development appears to offer the best opportunity for achieving this result.

In conclusion, we can see that it has been possible to study the underlying technology of breadmaking processes by considering the many variations which are used under four broad headings. Each breadmaking process offers unique advantages and disadvantages but there are few bread products that cannot be made with any one, once we as bakers have balanced our product requirements with our available raw materials and our process control needs.

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Chapter 3
Functional Ingredients

Dough Conditioners and Their Composition

The most basic bread dough one might use to produce a baked product would of necessity contain the following minimum ingredients: flour, water, yeast and salt. However, even those most skilled in the art of baking would agree that at the very least it would be difficult to make bread of a high, consistent quality from only these raw materials alone. The baker has always, where expedient, added small amounts of extra ingredients to enhance dough performance during processing or to improve the quality of finished bread. In the past these materials would usually be foodstuffs in their own right, such as fat, sugars, honey and malt flour. Although the principal benefits were probably considered to be related to the eating properties of the final baked article, it must have become apparent that it was possible to produce modifications to the dough itself during processing which might be equally beneficial in the finished product in terms of overall quality and shelf-life.

Many of the early baking systems had one common factor: between the mixing stage and the final shaping of the dough prior to final proof there was a relatively long resting phase. This was dictated by the need to generate a sufficient rate of gas production by the yeast in the dough to ultimately produce a well-risen loaf of acceptable specific volume. Once compressed yeast became available in the mid-nineteenth century the rate of gas production was no longer the rate-determining factor in bread production. At this point it became clear to all that there were other benefits to be derived from a significant resting period between mixing and final moulding and the concept of a bulk fermentation or floor time was evolved (Chap. 2). This fermentation stage not only enhanced gas production, but it also enhanced gas retention in the dough. Possibly it is for this reason that we have seen the name given to the group of small ingredients, additives and processing aids added to the dough to improve bread quality as, successively, yeast foods, flour improvers and currently as dough conditioners.

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The term ‘dough conditioner’ may be defined as any material or combination of materials which are added to yeast-raised doughs to enhance and control gas production or gas retention, or both or shelf life. The range and level of use of these substances is controlled by legislation in most countries. Over the last 25 years or so there have been a significant number of changes in both UK and EC regulations and the situation has reached a period of relative stability. It will, therefore, be assumed that at least for the foreseeable future the materials described will not disappear from the UK and EC permitted lists. Comparable regulations exist in other parts of the world.

The functional components in bread doughs can be divided for convenience into three main groups: ingredients, additives and processing aids. Ingredients may be described as materials which are foodstuffs in their own right, such as fats, soya flour, sugar and milk derivatives, although one might not always consume them directly in the form that they are added to bread dough. It is not the intention in this section of the book to discuss ingredients which characterize particular varieties of bread, rather to examine in some detail a small number of key ingredients which demonstrate specific functional effects in dough processing and on final bread quality.

Definitions of additives, legislation regarding their use and the labelling of such materials varies around the world and commonly the range of additives or flour treatment agents which might be used in bread and yeast-raised fine bakers’ wares are contained within relevant legislation (e.g. The Bread and Flour Regulations 1998; SI 1998, No.141). In the European Union harmonization of additives has been achieved. In theory the range of ‘additives’ which are now permitted for use in bread production has increased with the introduction of new forms of enzymes though in practice it is common to only use a small number of such materials to gain practical benefits.

The list of additives allowed in bread improvers used throughout Europe is much shorter than comparable lists on products from the USA. However, the ingredient listings on packaging do not tell the full story. For example, in the EU some additives may be classified as ‘processing aids’ and as such need not be declared on product labels, currently. In contrast, the addition of the enzyme *alpha*-amylase to bread dough in the USA would mean its appearance on the ingredient label. While non-declaration of enzyme additions is permitted under current EU regulations this may not be the case in the future. It is worth noting that many of the new enzymes which have been introduced as ‘processing aids’ in the EU will have been cleared through the ‘Novel foods and novel food ingredients’ regulations (EC 2000).

Ingredients

Fats

The soft fats, those with melting ranges similar to those of lard, have been traditional components of white bread in the UK, the USA (Pyler and Gorton 2008) and many other countries for at least the last 100 years. With animal fats now being out of favour, lard and partially hydrogenated fish oils have largely been replaced by partially hydrogenated vegetable oils with melting characteristics similar to those of lard, or in other cases they have been replaced with liquid vegetable oils, such as rape or soya. More recently there has been a move away from partially hydrogenated fats because of concerns regarding the levels of *trans* fats in diets. As already commented in Chap. 1 it is worth noting that in many bread products total fat levels are low and even if *trans* fats are present the contribution that they will make to the diet is relatively small. Fractionated and inter-esterified oils (a process catalysed by lipase) are now commonly used in bread products to provide both functionality in the breadmaking process and to add to the soft eating character of the crumb.

Fats may be described as ‘enriching agents’ in fermented products. They change the eating characteristics of bread and fermented goods giving a shorter, softer bite and at the same time a modest enhancement of the soft-eating shelf life. The effects increase with increasing levels of addition. The level of use of such fats varies widely from zero in some breads to about 1 % of flour weight for white pan breads and 2 % (or more) for wholemeal and other non-white breads. The fat level may increase to 10 % of flour weight or even higher in rich fermented products, such as rolls and buns, and speciality product like the UK hot-cross bun (a spiced and fruited bun traditionally associated with the Easter period). The higher levels of fat make a significant contribution to the tender eating quality and flavour of such products.

The effects of high melting point fats on dough properties and final bread characteristics are far more significant than those of the softer fats. The importance of high melting point fats was dramatically demonstrated in the research which led to the eventual development of the CBP (Chap. 2) as a commercially viable bread manufacturing process but had been appreciated for some time (Baker and Mize 1942). It was demonstrated that dough produced by the CBP and other no-time dough making processes which did not contain at least a prescribed minimum level of ‘solid’ fat (or emulsifier) at the end of final proof was highly unstable at this point, and gave bread with a blistered crust and little or no oven spring. The internal crumb structure was dark, open, coarse and the crumb was very firm, in fact all the symptoms of very poor gas retention (Chamberlain et al. 1965: Cauvain and Young 2001).

This effect can be graphically demonstrated by producing bread following the ‘classic’ CBP method and omitting fat from the recipe and then in successive doughs by adding controlled levels of various fats in a variety of dispersion systems. It was by empirical experimentation such as this in the 1960s that dough conditioner manufacturers devised, developed and refined their fat blends and at the same time established some of the basic rules regarding the nature of what came to be known as the ‘fat effect’ in CBP doughs.

The ‘rules’ for fat in no-time dough making systems can be summarized as follows.

- The ideal functional fat is a fully saturated one, with a chain length of C_{16}–C_{18}, i.e. tripalmin and tristearin with a melting point in the region of 55–60 °C (130–140 °F).
- Short-chain triglycerides, such as C_{12} and C_{14}, are much less efficient on a weight for weight basis and require more rigid control of dough and proof temperatures.

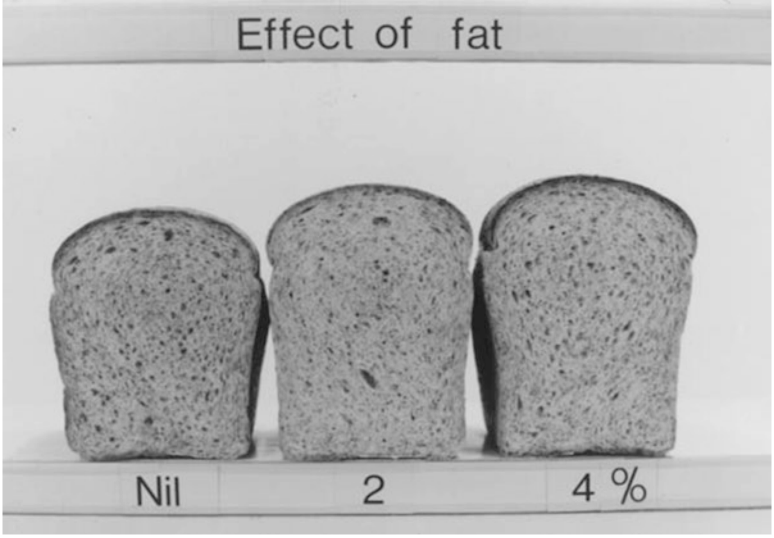

Fig. 3.1 Effect of fat in wholemeal (wholewheat) bread

- The fully saturated triglycerides must be in a highly dispersed form in the dough. A wide range of ingredients and techniques are capable of successfully dispersing the high melting point fat.
- The fat effect is not linear; too little fat produces bread of the same poor quality as bread without fat. There is then a dramatic increase in bread quality over a narrow range of increasing fat, after which there is little more to be gained in bread quality terms by further increases in the level of fat addition other than the softening effect on bread texture.
- The level of fat required to satisfy a dough in terms of the fat effect is relatively low and may be in the region of only 0.1–0.2 % of flour weight. It does, however, vary from flour to flour in response to factors which remain unclear and may rise to levels of about 1 % in white breads or 4 % in wholemeal (wholewheat) breads (Fig. 3.1).
- Fully hydrogenated fats based on fish and whale oils, even those with high melting points, are less efficient than fully hydrogenated animal and vegetable oils, presumably because the fatty acid chains are branched rather than straight.

It is therefore essential to ensure that, in all circumstances where a high melting point fat is the main lipid source in the dough, that a minimum level is added to allow for variations in flour characteristics. The reasons for the different responses by flours to fat addition in breadmaking are not fully understood though it is considered that the effect is more pronounced with no-time processes.

As the knowledge of the application of fats to the manufacture of baked products has continued to improve it has become possible to respond to the pressures of the market-place to deliver lower levels of functional and appropriate fats. Brooker (1996) and other sources identified the key properties and forms required for fats being used in no-time dough making processes. The identification of the critical crystal form for fats to deliver the required functionality in breadmaking and developments in fat processing technology have led to the supply of so-called liquid fats which essentially contain a small proportion of solid fat crystals suspended in a liquid oil. The use of such liquid systems has led to a reduction in the solid fat component in bread recipes without a loss of improving effect.

The role of fat in long fermentation systems is more difficult to demonstrate. Although many traditional recipes contain significant levels of fat, it is possible to produce bread by bulk fermentation or sponge and dough methods with acceptable gas retention properties without any fat in the dough, given sufficient skill and appropriate flour properties, as seen, for example, in the production of 'traditional' baguette in France. However, even in these situations a level of high melting point fat equivalent to that used in no-time doughs will have a very significant improving effect on bread quality.

Soya Flour

Full-fat enzyme-active soya flour as a functional dough ingredient has been known since the 1930s and for a long while it was used as the basis of flour improvers, in part to conveniently deliver the smaller quantities of functional ingredients (e.g. oxidising agents) and in part for its own functional effects in breadmaking (Brown 1993). It was considered to have two principal beneficial functions, both being due to a particular enzyme system present in the uncooked bean. This enzyme system, lypoxygenase, catalyses the oxidation of unsaturated fats or lipids by atmospheric oxygen to lipid peroxidases via a number of intermediate oxidation compounds. It is these intermediate compounds that are the functional entities in the dough.

The two major functions of enzyme-active soya flour are as a flour bleaching agent and as a mild oxidizing agent (Cauvain and Young 2001). The functional effect of soya flour as a bleaching agent is relatively simple and well understood. The intermediate oxidation compounds transfer oxygen from the atmosphere surrounding the dough and within the air bubbles incorporated during mixing to the yellow-coloured carotenoid pigment of flour. The oxidized products derived from these pigments are colourless, hence the dough is bleached—in much the same way as benzoyl peroxide functions in some dough making processes. In the UK, where benzoyl peroxide and chlorine dioxide are no longer permitted, the value of soya flour in breadmaking should not be underestimated. However, even with high levels of soya it is not possible with most dough mixing systems to achieve the same efficiency of bleaching as with benzoyl peroxide or chlorine dioxide. This is due largely to the limited availability of atmospheric oxygen. It is therefore not surprising that spiral-mixed doughs are more readily bleached than doughs mixed under partial vacuum in some mixers. The effect of soya in a CBP dough mixed under partial vacuum used on unbleached flour is still significant, possibly because the intense shearing action during the high-speed mixing process (Chap. 4) exposes the dough surfaces repeatedly to the limited amount of available oxygen in the mixer.

It has also been demonstrated that by increasing the contact between the dough surface and oxygen the bleaching effect of soya can be greatly enhanced. For example, CBP doughs mixed either in oxygen-enriched atmospheres or under pressure/vacuum systems, where a flow of oxygen is maintained across the surface of the dough during mixing (Chap. 4) will produce dough and hence bread crumb which is just as white as that produced by chemical bleaching, provided enzyme-active soya (soy) is included in the recipe.

The effect of soya (soy) flour as a mild oxidizing agent in dough is by no means as easy to demonstrate as its bleaching effect. The mechanism is complex. There may in fact be more than one route to the beneficial modifications of gluten via soya flour. The 'direct' route has been demonstrated by Frazier et al. (1973). This suggests that the effect of soya is dependent on the presence of polyunsaturated free lipid and that, via a rather complex mechanism, bound lipid is freed from specific sections of the gluten protein thereby allowing this protein to become more hydrophilic and hence to be able to help form the viscoelastic surface of the gas bubbles in the dough.

It is also becoming clear that as the number of flour treatment agents becomes ever more restricted, with the single remaining oxidant in many parts of the world being ascorbic acid, the role of soya flour in the efficient use of ascorbic acid is becoming more readily appreciated. In order for ascorbic acid to function in a dough it must first itself be oxidized to dehydroascorbic acid (Cauvain and Young 2001). Where the supply of oxygen is limited, for example in a dough mixed under partial vacuum, or in a conventionally mixed dough where yeast activity begins to restrict the availability of oxygen, soya flour is a valuable adjunct to the oxidation system. This combination has proved to be beneficial in long fermentation processes.

The addition of soya four to bread recipes should be accompanied by an increase in the level of recipe dough water, typically equivalent to half of the soya flour weight. Commonly levels of soya flour addition will be limited to around 2 % of the flour weight, otherwise there may be adverse aroma and flavour effects associated with the dough and bread.

It is perhaps appropriate to comment on the subject of the source of the soya. Increasingly soya crops in many parts of the world are derived from genetically modified (GM) seed. At the time of writing there is no evidence which shows that growing GM has any adverse effects on the environment or the behaviour of the subsequent products in the manufacture of bread. However, in some parts of the world, most notably within the EU, consumer opposition to the growth and use of GM soya has had the impact of reducing the use of soya flour, or in some cases its elimination from bread recipes.

Additives

Emulsifiers

Diacetylated tartaric acid esters of mono- and diglycerides of fatty acids (*DATA esters, E472*(*e*)). The legal status of DATA esters in the EC is that they are permitted at a QS (*quantum satis*) level in all types of bread and fine bakers' wares. The term 'DATA ester' (DATEM) is a generic one covering a range of similar materials which vary due to the nature of the fatty acid and the ratio of mono- to diglyceride (Gaupp and Adams 2004). There are also further significant variations due to the level of esterification by the diacetylated tartaric acid. The physical forms vary from an oily liquid to a fairly free-flowing powder depending on the degree of saturation of the base fat. In many commercial preparations there are at least five major and many more minor components. There are a limited number of types of DATA esters based on low melting point fats or oils which are used as components of paste (fat-like) or fluid (pumpable) dough conditioners. In the UK it is now usual for DATA esters to be based totally on non-animal raw materials, including the glycerol used in the preparation of the monoglyceride prior to the final esterification. DATA esters are commonly used in the powder form as part of a composite improver or maybe suspended in oil in liquid-based improvers.

The most basic description of the function of DATA esters is that they enhance gas retention when incorporated into most any yeast-raised wheat flour-based dough. There is a fairly direct relationship between the level of addition and the enhancement of gas retention up to an optimum level, after which there is a plateau followed by a slight reduction of effect at excessive levels of use. The final level of bread quality enhancement is far greater than that of fat. As to the mechanism, one can only select from the literature the one which appears to fit most readily the empirical observations. There is strong evidence that when DATA esters are incorporated into bread doughs they bond rapidly and totally to the hydrated gluten strands. The resultant gluten network is not only stronger but is more extensible and has a more resilient character. This produces a dough which has a gas bubble network with small-sized, strong and extensible gas cell walls. There are three major areas in which this property can be exploited: in white bread, in morning goods (e.g. rolls) and in wholemeal (wholewheat), multigrain and seeded breads.

Use of DATA esters in white bread. When the flour used in such breads contains an inadequate amount or less than ideal quality of protein, the inclusion of DATA esters assists in stabilizing the dough at the end of final proof stage and still provides a dough with reasonable oven spring. The baked bread is of higher specific volume with a more symmetrical appearance. Internally it has a finer gas cell structure with thinner cell walls, and because of this the bread crumb appears whiter, it has a finer, more even texture, feels softer and is more resilient. Typically levels of addition will be less than 0.3 % of the flour weight.

Use of DATA esters in high-volume bread, buns and rolls. The aim in the manufacture of these products deliver a high specific volume in the product whilst retaining a relatively fine, even structure. These properties are mainly obtained by increasing proof volume to a level which might be considered excessive by normal standards. The proof times for such products tend to be 50–60 min, and the recipes typically contain higher yeast levels. Proof is followed by significant but controlled oven spring. This type of product requires a good-quality bread flour as a base to accompany greater gas retention contributed by the emulsifier. The doughs benefit from the improved proof stability conferred by the emulsifier, especially when the low-density doughs are transferred from proof to oven and in the early stages of baking. In the baked product the quality characteristics benefit in a manner similar to those described above for white bread and in addition with the better quality flour which is used, the baseline quality is higher and hence the finished product is of enhanced quality.

Long proof fermented products. This group covers products ranging from baguettes to Scottish morning rolls and includes overnight proved rolls. For such products DATA esters are required to provide proof stability over periods between 2 and 16 h at low proof temperatures. The overall flour quality varies in this product grouping between low protein flours for baguettes and high protein flours (in some cases with additional gluten) in overnight Scottish morning rolls. All these products require a dough which is stable to extended and often variable proof conditions. For baguettes it must be possible to cut the dough at the end of proof without collapse. In all cases stability is required to ensure a lively movement in the oven to produce an article of high specific volume—baguettes in particular must demonstrate a good 'burst' at the cut (Collins 1978).

DATA esters in wholemeal and seeded breads. A major difficulty in the commercial production of these types of bread is that the particles of bran and flakes of wheat and seeds disrupt the gas cell network in the dough (Thompson et al. 2010). One approach to overcoming this problem is the addition of extra wheat gluten to the recipe. An alternative is the use of DATA esters or a combination of emulsifier and wheat gluten. The DATA esters confer enhanced gas retention with a finer, more even texture and importantly once again, a thinner gas cell wall structure. The resulting bread not only has increased volume but it also has a much finer, more even crumb structure, a better internal appearance and a softer, less harsh eating characteristic. DATA esters have no effect on the properties of starch–water mixtures and therefore will not directly modify or reduce staling, or staling rates (Chap. 10). They do have a beneficial effect on soft-eating shelf life due to their ability to increase finished product volume and to facilitate a fine, even, thin cell wall structure in a wide range of products.

Sodium stearoyl-2-lactylate (*SSL, E482*). In the UK SSL is permitted for use in bread up to a level of 3 g/kg in bread and 5 g/kg in fine bakers' wares, based on finished product weight. This is a less complex material than DATA esters, although the number of lactic acid residues may vary, usually between two and five per molecule (Boutte and Skogerson 2004). SSL is a white solid with a comparatively high melting point and can be added to dough in powder form, either alone or as part of a compound dough conditioner. It is miscible with fat and therefore is an ideal component of fat-based concentrates, particularly for semi-rich and rich fine bakers' wares, including rich buns and doughnuts. SSL has some of the properties of DATA esters. It enhances gas retention in the dough but weight for weight it is less efficient in this function. At the same time it does demonstrate genuine soft-eating shelf life extension. It is capable of binding to amylose in a manner similar to that of distilled monoglyceride, which must account for its crumb softening effect.

In practice in the UK, SSL is seldom used in the manufacture of standard bread or in lean or crusty recipes. Bakers tend to prefer DATA ester-based dough conditioners for maximum gas retention and add distilled monoglyceride at the desired level when extra softness is needed. However, in semi-rich and rich yeasted goods ranging from soft baps to hot cross buns, and in yeast-raised doughnuts, SSL is often the preferred emulsifier. It gives some of the proof stability of DATA esters, but with a more limited and controlled oven spring resulting in baked (or fried) items with adequate volume (in the case of doughnuts with less blistering in the fryer) and a white, fairly dense crumb with a soft, moist-eating mouth feel and an extended soft-eating shelf life.

The ideal mode of use for SSL is a part of a compound fat-based dough conditioner together with salt, sugar and flour treatment agents. The range of end products to which it is best suited is that containing both fat and sugar. These two factors combine to make SSL an attractive emulsifier in quite a wide range of baked goods, which is why its use continues to grow in the UK market. In the USA and elsewhere, SSL may be replaced with the calcium form, CSL, and used at levels similar to that for SSL. The overall effects of CSL in breadmaking are similar. There has been increased interest in CSL as an SSL replacer with the drive to reduce sodium levels in bakery products for health reasons (cf salt-sodium chloride, see below).

Distilled monoglyceride (*E471*). In the EC this category of emulsifiers is permitted at a QS level in all breads and fine bakers' wares. It is used as a crumb softener and functions by binding to the amylose fraction of the wheat starch at the elevated temperatures typical of baking. In doing so it slows down retrogradation of the starch during cooling and subsequent storage, hence it can be claimed that it actually retards staling (Chap. 10). Distilled monoglycerides have a long history of use as a bread improver with the hydrated gel form (see below) having been prepared directly in the bakery before addition to the dough.

There is no doubt that incorporation of monoglyceride into a recipe does extend the softness of the crumb of yeast-raised products, particularly during the first 3 days after baking. The difference is sufficient to be appreciated by the average customer in a wide range of products. For this reason they may be used cost effectively as partial fat replacers. The distilled monoglycerides function extremely well in this role but there is a temptation, particularly in semi-rich and rich fermented goods, totally to replace the fat by what is considered to be an appropriate level of monoglyceride. Such actions can result in products in which the crumb is indeed very soft immediately after baking, but over the next 24 h becomes weak, dry and crumbly. In products other than standard pan bread it is not advisable to replace more than 50 % of the fat in the original recipe.

The most functional fatty acid base for crumb softening is stearic acid which for baking ingredients has a relatively high melting point, 55–65 °C (130–150 °F), and therefore to be functional it must be made water dispersible in some way and must be in the correct crystalline state (Moonen and Bas 2004). For these reasons, distilled monoglycerides are offered to bakers in two distinct forms: as hydrates in water and emulsions, and as water-dispersible powders. Hydrates are oil in water emulsions produced by blending the melted emulsifier and hot water together with a low level of a stabilizer and then cooling, with stirring under carefully controlled conditions to form a stable emulsion. If formed correctly, this emulsion will remain in the correct crystal phase permanently. The emulsifier level in such hydrates is in the region of 20–40 % by weight. It is also possible to combine high melting point fats into such products to give them a dual function.

There are no set rules for levels of addition of hydrates; however, the following can act as a basic guide:

- in standard white bread, up to 1 % of hydrate by weight of flour should be sufficient to significantly extend shelf life;
- in rolls and buns containing fat, add 50 % of the original level of fat in combination with 25 % of the original level of fat hydrate;
- if a water-dispersible powder is used then it should be added in the same way, but assume that one part of powder is roughly equivalent to four parts of hydrate.

When used on its own the main function of distilled monoglyceride in yeast-raised doughs is to soften the crumb of the product post-baking and assist in the retention of the extra softness for up to about 3 days; it is commonly considered to be an anti-staling agent (Chap. 10). The addition of monoglycerides has not generally been considered to enhance dough gas retention and not improve proof stability, product volume, crumb colour or crumb texture unlike DATA and SSL. A view is that those monoglyceride hydrates which exhibit some of these latter properties do so mainly because of the high melting point fat which is contained within the emulsion. However, Moonen and Bas (2004) considered that the addition of 0.2 % Myvatex Mighty Soft (a proprietary form of monoglycerides) did improve dough stability in a shock test at the end of proof. The apparent differences in the performance of monoglycerides with respect to dough stability may well be related to the dough making process employed.

Moonen and Bas (2004) illustrate an interesting application of powdered monoglycerides in retarded dough as a means of eliminating the formation of translucent spots on retarded breads (see also Chap. 6).

Lecithins (*E322*). The legal status within the EC for lecithins is that they are permitted QS in all types of bread and fine bakers' wares. The term lecithin covers a group of complex phospholipids found naturally in a wide range of animals and plants (Bueschelberger 2004). The most usual source of lecithin used in the baking industry is soya (soy). It is extracted as a viscous liquid which is approximately 65 % phospholipid and 35 % oil. The liquid is blended with gypsum or wheat flour to produce a free-flowing powder which can then form the base of a composite dough conditioner. Lecithin is very popular in France as the principal lipid source in baguettes and other crusty breads. The reasons for its popularity are in part historical and in part technical. It was, and still is, the only legal source of lipid permitted for a traditional French baguette (as defined within the EC). It is capable of enhancing gas retention in a dough to some degree, although in this respect it is far less efficient than DATA esters or SSL. At the same time it has a very different effect on crust character. DATA esters in particular produce crusty baked goods with a thin, 'egg-shell' crust which tends to become leathery during storage. Lecithins give a thicker denser crust which may not look as attractive but tends to retain its crispness qualities for longer.

Flour Treatment Agents or Oxidizing Agents

Ascorbic acid (*vitamin C, E300*). In many parts of the world ascorbic acid (AA) is the only permitted oxidizing agent in breadmaking; typically it is used at levels between 100 and 300 ppm flour weight. To understand the beneficial effects of oxidants in the breadmaking process it is necessary to describe briefly the basic structure of a wheat flour-based dough. The key factor is the wheat protein. When mixed with water wheat protein has a property unlike almost any other plant protein to form viscoelastic sheets (Belton 2012). The hydrated wheat starch granules are embedded in this structure which forms at the surface of minute gas bubbles produced in the dough from occluded air present in the flour particles prior to mixing. The two major components of wheat protein are usually described as glutenin and gliadin. Glutenin consists of high molecular weight proteins in which individual polypeptide chains are cross-linked by the disulphide bonds of the amino acid cysteine. Gliadins are composed of lower molecular weight proteins in which the cysteine cross-links are intra- rather than inter-molecular (Fig. 3.2).

Once hydrated both classes of protein are to a high degree in the form of either *alpha*-helix or random helix. In addition to the cross-linked cysteine present in wheat protein there are a number of cysteine amino acids present in the reduced form as shown in Fig. 3.3. The ratio of —S—H groups to —S—S— bonds is approximately 1:20. The reactions which occur between —S—S— and —S—H links during mixing and bulk fermentation or mechanical dough development are varied and complex, and discussed in greater detail in Chap. 11 and elsewhere (2012).

At this stage we need consider only the most basic change which occurs in the dough, which is a reduction in the stresses experienced in the gluten network and is commonly referred to as the disulphide-sulphydryl interchange. This exchange is illustrated in Fig. 3.3. It occurs to some degree during conventional (low-speed) mixing, but at much more rapid rate during mechanical dough development or spiral

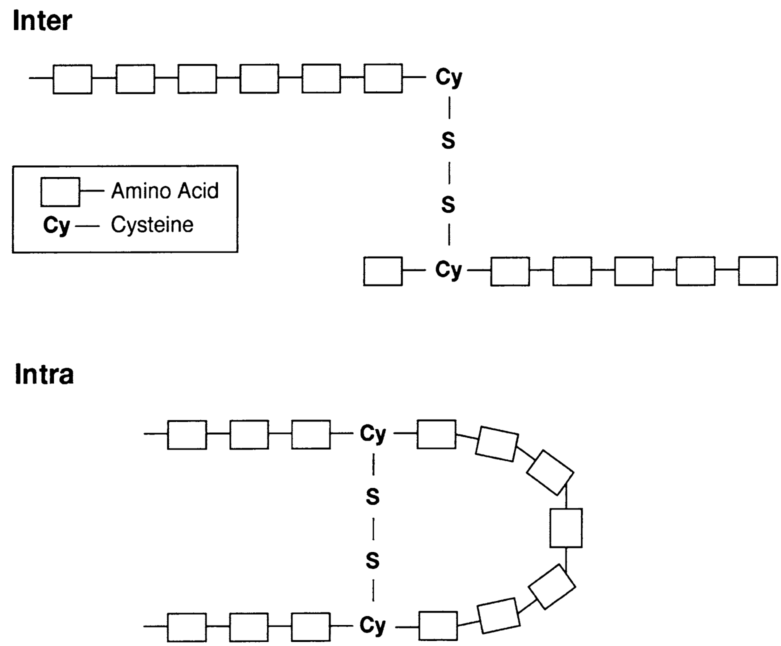

Fig. 3.2 Representation of cysteine crosslinks in gluten

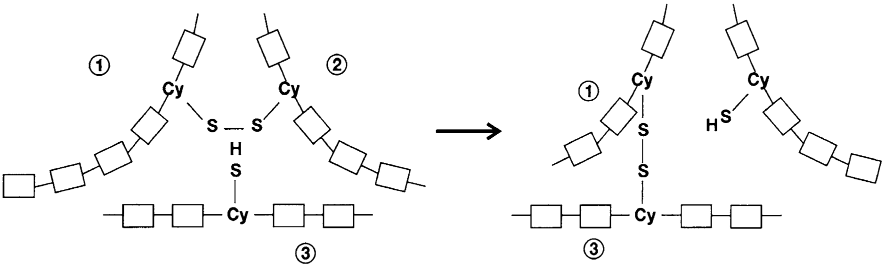

Fig. 3.3 Representation of disulphide–sulphydryl interchange

mixing. Introducing an oxidizing agent into the system complicates matters further. It is now possible to oxidize the —S—H group, either to form new cross-links between protein chains or to oxidize the —S—H group to SO_3H, which is no longer capable of undergoing disulphide–sulphydryl interchange.

The possible effects of ascorbic acid with respect to disulphide bond formation in dough can be listed as follows.

- Oxidation of water-soluble —S—H groups to remove them from the system. This would benefit the dough structure by preventing them from preferentially reacting with the —S—H groups of the glutenin molecules exposed during the development period.

- Causing a —S—S— bond to be formed between a water-soluble protein —S—H group and a glutenin —S—H group. This might well weaken the dough structure.
- Causing a —S—S— bond to be formed between two of the glutenin —S—H groups exposed during the development period. This would increase the elasticity of the dough structure.
- The direct oxidation of a —S—H group in a glutenin molecule to a stable form which is then unable to take part in further interchange reactions.

Thus the role of the oxidant is thought to be first to remove the water-soluble protein —S—H groups from the system. These groups will be the most readily reactable ones in the system, so that this must be the major reaction. The result is a shift of the balance of the reactions of glutenin molecules towards the formation of inter-glutenin —S—S— bonds rather than glutenin-soluble protein —S—S— bonds, thus producing a more elastic structure. It will also increase the degree of reaction of the 'masked' glutenin —S—H groups exposed during development, both to increase the number of —S—S— linkages and also to stabilize some as a non-reactive form. The overall effect is to produce a stable, stronger, more elastic gluten network capable of expanding without rupture, during the rapid growth of the gas cells in the early part of the baking process.

Bulk fermented doughs are not subjected to the same conditions of stress as mechanically developed doughs since —S—H groups are not exposed to oxidation to the same degree. They are far less likely to react with small protein subunits to weaken the structure and so require far lower levels of oxidant to obtain optimum development (as defined by maximum product volume with such breadmaking processes). The optimum level of oxidant is therefore to a large extent determined by the dough processing system.

The use of ascorbic acid presents a further complication. Chemically it is a reducing agent and can only function as an oxidizing agent in a dough after it has been itself oxidized to dehydroascorbic acid, and to function efficiently requires the availability of atmospheric oxygen (Collins 1994; Cauvain and Young 2001; Weiser 2012). A breadmaking system which has significant needs for oxidation is the CBP which has often been carried out using the application of partial vacuum during mixing to ensure a fine and uniform cell structure in some final products (Chap. 2). Coupled with this is the fact that in any yeasted dough the available oxygen is rapidly taken up by the yeast (Chamberlain and Collins 1979) and it is easy to deduce that ascorbic acid is not the ideal choice of single, all-purpose oxidant in baking industries using mechanical dough development processes like the CBP. Ascorbic acid is a quite rapidly acting oxidizing agent and it is difficult to over-treat with no-time dough making systems because the potential oxidation effects are limited when there is no available oxygen.

Over-treatment is possible when ascorbic acid is added to doughs which are then bulk fermented. In this case over-treatment is not necessarily through over-oxidation. The effect of adding ascorbic acid to doughs which are given 3 h bulk fermentation is illustrated in Fig. 3.4. Even when added at 20 ppm flour weight

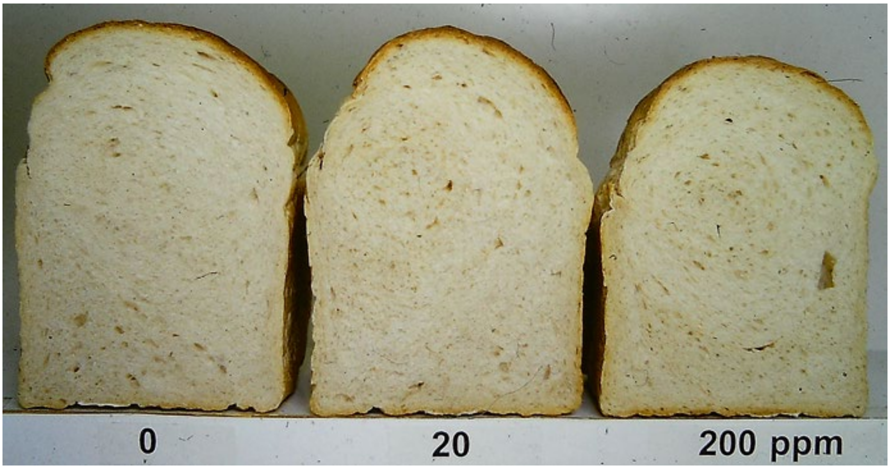

Fig. 3.4 Effect of ascorbic acid when used in bulk fermented dough

there is a noticeable loss of loaf height which becomes even greater when the dosage is raised to 200 ppm. In addition to loss of bread quality the doughs with high levels of ascorbic acid lack elasticity and are difficult to process. Some loss of bread quality may also be experienced if ascorbic acid is present in the sponge in a sponge and dough process.

In the past many bakers had become used to flours destined for use in bulk fermentation systems which contained a low level of potassium bromate added at the flour mill. Potassium bromate is a slow-acting oxidant which functioned late in the process in the absence of oxygen; typically the late stages of proof and early stages of baking which contrasts with the rate of reaction for ascorbic acid in its ‘oxidation’ role during mixing. Once in an anaerobic environment the oxidation potential of ascorbic acid may be lost but it still has the potential to react with flour proteins in a reduction role. There may be some further oxidation if the dough is re-mixed at any stage and perhaps a little when dough surfaces are exposed during dividing and processing but such potential complex effects are not understood.

To summarize:

- Ascorbic acid is the only chemical oxidizing agent currently available in the European baking industry and many other parts of the world. This situation is very unlikely to change.
- It requires atmosphere oxygen and ascorbic acid esterase (available in the flour) to function.
- It is a large molecule and may not be able to oxidize a number of —S—H groups which are ‘protected’ by the gluten molecule.
- In no-time dough systems a high level of addition is required (between 100 and 300 ppm by weight of flour).

- Higher levels of addition may be beneficial in frozen dough and some speciality products.
- In CBP doughs mixed under partial vacuum, it very quickly becomes unable to access the atmospheric oxygen it requires to function effectively because of the competition from the yeast (Cauvain and Young 2006).
- In bulk fermentation systems it can only function efficiently in the mixer; later in the process it lacks the atmospheric oxygen to convert it to the dehydro-form and as levels of addition increase it can lead to loss of product volume.

Against any of its shortcomings ascorbic acid does have a number of significant advantages.

- It is vitamin C and therefore it is unlikely that it will be removed from the list of permitted additives for bread.
- The use of high levels of ascorbic acid in no-time dough does not lead to the problems associated with over-treatment, such as those which might occur with azodicarbonamide or potassium bromate.
- The efficiency of ascorbic acid is greatly enhanced by the use of spiral mixers or by the newer CBP-type mixing systems, such as oxygen enrichment or pressure/vacuum mixers in which a supply of oxygen to the dough surface is maintained for part of the mixing cycle (Chap. 4).

It is possible to enhance dough characteristics using emulsifiers and enzymes to complement the action of ascorbic acid, as typically occurs with composite improvers. As discussed briefly above (see also Chap. 4), it is also possible to modify the mixing and dough development system to optimize the functions of ascorbic acid. In these circumstances the production of bread and other yeast-raised goods of high quality with ascorbic acid as the sole chemical oxidizing agent is possible. It may, however, require rebalancing of formulations or modification of production techniques, and more care and attention to detail on the part of bakers themselves to obtain optimum results. For example, through better control of dough processing times and temperatures.

L-*Cysteine* (*920*). This is an amino acid which due to its —S—H group can act as a reducing agent directly on the disulphide bonds in the gluten structure of the dough. It is commonly used in the hydrochloride form. It was first used in the UK and Eire as a component of the Activated Dough Development (ADD) process as a mixed oxidant in conjunction with ascorbic acid and potassium bromate (Brown 1993). The ADD process allowed bakers to obtain some of the processing advantages of no-time doughs with low-speed mixers. L-Cysteine relaxes the gluten structure during the mixing process, enhancing dough development. ADD was largely abandoned due to the loss of potassium bromate from the list of permitted additives in the UK and the progressive replacement of low-speed mixers by spiral mixer types.

L-Cysteine does have a role in the baking industry. It may be useful at a low level in white bread to help to reduce (but not eliminate) streaks and swirls in the bread crumb cell structure generated at the moulding stage (see also Chap. 4). In pinned morning goods, such as Scottish morning rolls and soft baps, and with hamburger buns manufactured using plants with little or no first proof, it can greatly ease stresses within the dough reducing misshapes, cores, streaks and swirls in the internal crumb structure. It can also reduce the incidence of holes under the top crust in such products.

It is beneficial in increasing flow in CBP and other no-time-dough processes when used for manufacturing hamburger buns with indented pans and when using short first proof systems, usually designed for sponge and dough processes (Chap. 9). It can also be helpful in the manufacture of pizza bases, which must return to their original shape after sheeting or pressing (often such doughs contain a high level of rework which increases the resistance of dough to deformation at pressing).

Reducing agents are sometimes used to modify the behaviour of flours when the protein content is high or where the rheology of the doughs is unsuitable for the breadmaking process being used. In North America the treatment of strong flours which are said to be 'bucky' with a reducing agent can be relatively common. In such cases the addition of a reducing agent may be used to improve moulding behaviour. In the CBP L-cysteine may be used to reduce the work input requirement and thus assist with control of final dough temperature. However, using L-cysteine in this way tends to be less effective in conjunction with AA.

'Natural' alternatives to L-cysteine are available which are based on inactivated yeast (see below). In this case the reducing effect if based on a mixture of glutathione and proteolytic enzymes released from the disrupted yeast cells.

Oxidizing agents in the USA. The list of permitted oxidizing agents which may be used in the USA is somewhat longer than that within the EC. At the time of writing the use of potassium bromate is still permitted (and in Japan). Potassium bromate has a long history of use in the USA stretching back to 1914. Concerns over the use of potassium bromate in breadmaking have centred around the levels of unreacted residue in the baked loaf. During the breadmaking process the main reaction as the result of oven heat is to convert the bromate to the harmless bromide. As the result of extensive investigations and the development of new analytical testing methods (Himata et al. 1997, 2000), a protocol for the safe use of potassium bromate was established and jointly issued as a monograph by the American Bakers Association and the American Institute of Baking (2008). This gives a safe limit for residual potassium bromate of 20 ppb of final products and identifies practical measures for bakers to take. Some bakers in the USA use potassium bromate at reduced level of addition while others have stopped using it. Unlike the situation in Europe, North American bakers have not routinely used ascorbic acid, and in addition, have access to the use of salts of iodine, e.g. potassium iodate, acetone peroxide (Pyler and Gorton 2008) and azodicarbonamide (Weiser 2012). The latter oxidising agents are not limited to any great extent by available oxygen for their action in the dough and are suited to the sponge and dough processes in common use in North America and elsewhere (Chap. 2).

Preservatives

The preservatives permitted for use in bread and fine bakers' wares are commonly limited by legislation (e.g. in the UK by The Miscellaneous Food Additives Regulations 1995). The preservatives permitted in the UK are summarized in Table 3.1, and this list includes materials that are in common use around the world. The permitted preservatives are intended to inhibit the growth of moulds and thermophilic bacteria (Chap. 10). Of the three groups of preservatives listed in Table 3.1, sorbic acid and its salts are of least value in bread and yeast-raised goods, because of their detrimental effects on dough characteristics rather than their efficiency in the inhibition of microbial growth. The levels of use required to give any significant increase in shelf life result in doughs which are sticky and can be very difficult to process. The resultant baked product has a poor volume and a coarse, open cell structure. To overcome the negative effects encapsulated sorbic acid may be added to the dough and in some cases sorbic acid or its salts may be sprayed on the surface of products after leaving the oven or the cooler.

If the customer is prepared to accept the presence of a preservative in the product, propionic acid or its salts provide the most effective protection against mould growth. The usual choice from this group is calcium propionate. The limits of use in the defined classes of baked goods are lower than those previously permitted but are not as restricting as they might first appear. The levels refer to the free acid and they are based on the total weight of the baked product. There is a very significant loss in propionic acid level during baking. In practice the usual maximum levels of calcium propionate presently used in the EU, i.e. 3000 ppm by weight of flour, should give adequate protection and remain within the law for all classes of baked products. At this level the mould-free shelf life can be extended by 2–3 days. It is usual when adding calcium propionate to a dough to include it as part of a composite dough conditioner. This may be a little more expensive but it offers some advantage since in its pure form, calcium propionate is not a pleasant material to handle. As part of a composite improver it is less likely to irritate the eyes and lungs. It can be incorporated into bulk handling systems for dough conditioners, so that the need for bakery staff to come into direct contact with it is virtually eliminated. The risk of weighing errors is reduced, together with the possibility that it might be omitted totally in some dough or added at above the permitted levels in others. Where significant protection against microbiological spoilage is required it is best to use calcium propionate at a level of at least 2000 ppm by weight of flour and to use it all year round, since this offers protection against both moulds and thermophilic bacteria.

Many bread producers do not wish to see preservatives included on the labels of their baked goods and the only material they will accept is acetic acid (vinegar). It is usually added in the form of a 12.5 % solution at levels of about 0.6–0.9 % based on flour weight. It is much less efficient in inhibiting mould growth than calcium propionate, although it does offer some limited protection. It has more benefit in inhibiting the growth of thermophilic bacteria provided that it is added at

Table 3.1 Preservatives and their use

Product category	Maximum permitted level (ppm of finished product)	
All bread and fine bakers' wares	Acetic acid (E260) Potassium acetate (E261) Sodium diacetate (E262)	QS
Prepacked sliced and rye breads	Acetic acid (E260) Potassium acetate (E261) Sodium diacetate (E262)	QS
	Sorbic acid (E200) Potassium sorbate (E202) Calcium sorbate (E203)	2000
	Propionic acid (E280) Sodium propionate (E281) Calcium propionate (E282) Potassium propionate (E283)	3000
Part-baked, prepacked and energy-reduced breads	Acetic acid (E260) Potassium acetate (E261) Sodium diacetate (E262)	QS
	Propionic acid (E280) Sodium propionate (E281) Calcium propionate (E282) Potassium propionate (E283)	2000
Prepacked fine bakers' wares with $a_w > 0.65$	Acetic acid (E260) Potassium acetate (E261) Sodium diacetate (E262)	QS
	Sorbic acid (E200) Potassium sorbate (E202) Calcium sorbate (E203)	2000
	Propionic acid (E280) Sodium propionate (E281) Calcium propionate (E282) Potassium propionate (E283)	3000
Prepacked rolls buns and pitta	Acetic acid (E260) Potassium acetate (E261) Sodium diacetate (E262)	QS
	Propionic acid (E280) Sodium propionate (E281) Calcium propionate (E282) Potassium propionate (E283)	2000

such a level that it lowers the pH of the dough to about 5.2 (note the presence of calcium carbonate in some flours may limit the level to which the dough pH can be lowered).

It should be noted that preservatives can only inhibit microbial spoilage; they do not destroy microorganisms. The essential basis for baked goods with an adequate shelf life is a well-designed, clean, well-run bakery with a thorough, appropriate hygiene system correctly implemented and closely monitored. In this context many bakeries have moved to the implementation of so-called ‘clean room technology’ where physical efforts are implemented in the building design which limit the contamination with microorganisms from air (by using filters), equipment and workforce.

Processing Aids

Enzymes Used in Baking

Enzymes are specialised proteins which act as biological catalysts and greatly accelerate the rates of biochemical reactions in plant and animal systems. They are becoming increasing common components of bread improvers. While their application as bread improvers has been known for some while, recent changes in understanding and regulation have increased their use. For example, the only two classes of permitted enzymes in the UK were *alpha*-amylases and proteinases. In 1995, after a long campaign by the UK baking industry, hemicellulases were added to that list. In 1996 the Bakery and Allied Traders Association succeeded in persuading the Ministry of Agriculture, Fisheries and Food in the UK to deregulate totally the use of enzymes in bread and flour in the UK. However, this act of deregulation was accompanied by the strong suggestion that any use of new enzymes in bread or flour should be preceded by an examination of each preparation by the Committee on Toxicity (COT) in the UK regarding all aspects pertaining to food safety. With the harmonization of regulations throughout the EU the range of enzymes permitted for the manufacture has increased but as noted above, the introduction of ‘new’ enzymes for breadmaking still requires regulatory approval.

In nature enzymes are usually contained within microbial cells and may be released by the organism and move through the cell wall. The manufacture of enzymes which are used as processing aids in food production, including baking, is a highly specialised business. Classically enzymes were extracted from plant and animal tissue but today the main approach is based on microbial fermentation with selected microorganisms being grown in very specific conditions of temperature and pH (Charalampopoulos 2012). After the microbial fermentation process is completed the mixture of microorganisms and enzymes which have been released are concentrated and refined through filtration to isolate the specific enzymes. The reactions of enzymes are very specific and can be likened to the principle of a ‘lock and key’ with the substrate (the material enzyme will act on) being the lock and the enzyme the key; in essence each of the combinations of lock and key are unique. Kornbrust et al. (2012) list the factors which affect enzymic reactions in breadmaking as:

- Substrate concentration
- Enzyme concentration
- pH and temperature
- Water content/water activity (a_w)
- Co-factors (non-protein molecules, often metal ions)
- Co-enzymes which are small organic molecules loosely bound to an enzyme and transport chemical groups from one enzyme to another
- Inhibitors which are present in plants and which have evolved to protect plants from microbial

Alpha-Amylases

The *alpha*-amylases are a range of enzymes which catalyse the same basic reaction, namely the breaking of hydrated starch molecules, both amylose and amylopectin un-branched and branched long-chain maltose polymers, into short-chain un-branched molecules known as dextrins. In combination with *beta*-amylase (an enzyme present in abundance in wheat flour) which attacks the ends of the amylose and amylopectin chains breaking off individual maltose sugar molecules, and given sufficient time and the right conditions, they are capable of converting starch almost totally to maltose (Fig. 3.5). Each time a starch chain is broken by *alpha*-amylase two sites are created at which the *beta*-amylase can function. It is therefore the level of *alpha*-amylase which is the rate-determining enzyme in the system.

Most wheat flours contain an adequate level of *beta*-amylase, but usually only a low level of natural (cereal) *alpha*-amylase and so it has become common practice to make adjustments to the amylase levels through additions of suitable materials. The effect of the addition of *alpha*-amylase to dough is dependent on at least three factors: the level of addition, the dough temperature and the heat stability profile of

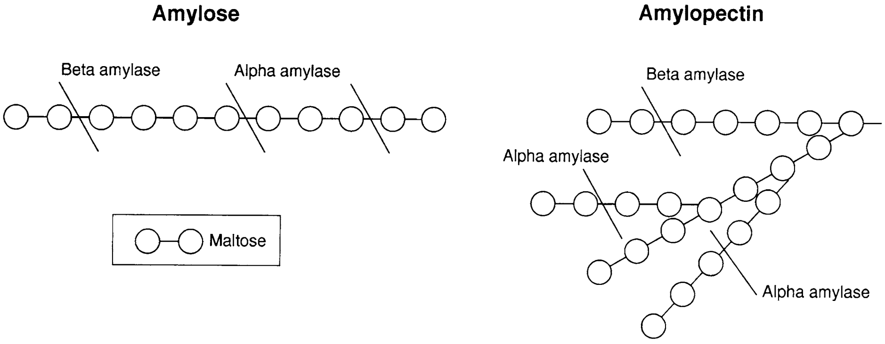

Fig. 3.5 Representation of the actions of *alpha*- and *beta*-amylases on starch

the particular type of *alpha*-amylase (Miller et al. 1953). Generalized heat and activity profiles are given for a range of types of *alpha*-amylases in Fig. 3.5.

In the milling of wheat to flour for bulk-fermented dough, it was usual for the miller to add to the flour a low level of fungal *alpha*-amylase. This addition, in the region of 5–15 Farrand units (FU) (Farrand 1964), was to ensure the presence of an adequate amount of sugar for the yeast during final proof and in the early stages of baking. It was necessary to control both the damaged starch (Chap. 12) and the fungal *alpha*-amylase level to prevent excessive hydrolysis of starch, which leads to doughs becoming progressively softer and stickier throughout fermentation and subsequent processing. In wheat flour the level of cereal *alpha*-amylase is determined by the Hagberg Falling Number test (Cauvain and Young 2009).

Fungal *alpha*-amylase is commonly preferred to cereal *alpha*-amylase derived from malted wheat or barley because of its lower heat inactivation temperature. This reduces the risk of the formation of an excessive level of dextrins in the bread during the later stages of the baking process. If there is an excess of dextrin formation, the baked loaf will have a dark crust and the internal cut surface will feel sticky to the touch. Problems even arise at relatively low levels of dextrin formation in sliced bread. The dextrins rapidly coat the slicer blades and it becomes progressively more difficult to achieve a clean cut. Eventually the bread becomes torn rather than cut and begins to compress and collapse at the in-feed to the slicer (Chamberlain et al. 1977). This difference is of much greater significance in no-time doughs, whether prepared in spiral or high-speed mixers.

In many production units using the CBP, particularly when using flours which are lower in protein quantity and quality, it has been found beneficial to incorporate into the dough conditioner high levels of fungal *alpha*-amylase. Often these additions are in the region of 100–150 FU (Cauvain et al. 1985). In these circumstances the enzyme is not incorporated into the dough to provide a source of sugar for the yeast, but for its effect on loaf volume. The effect on dough characteristics and finished bread quality can be dramatic. Oven spring and hence final loaf volume can be considerably enhanced. The cut surface is whiter with a finer cell structure and a softer, more tender crumb. It has been suggested that the increased oven spring is due to the action of fungal *alpha*-amylase on starch in the loaf in the temperature range of 55–60 °C (130–140 °F). At this point the hydrated starch begins to gelatinize. It is therefore very vulnerable to attack by *alpha*-amylase. If there is the correct balance in the system it is possible to delay the gelling of the starch within the baking loaf long enough for it to continue to grow in the oven for a little longer than would otherwise be possible. Observations on doughs containing high levels of *alpha*-amylase compared to a control of the same composition but containing little or no amylase confirm that the loaf containing the higher amylase levels does in fact continue to expand further and set a little later into the baking process (Cauvain and Chamberlain 1988).

The reason why cereal *alpha*-amylase represents a far greater risk than fungal *alpha*-amylase becomes apparent if one compares the heat inactivation curves of the two enzymes (Fig. 3.6). Bearing in mind the additional factors that both yeast activity and *beta*-amylase activity cease by 55 °C, it is clear that in a baking loaf the cereal

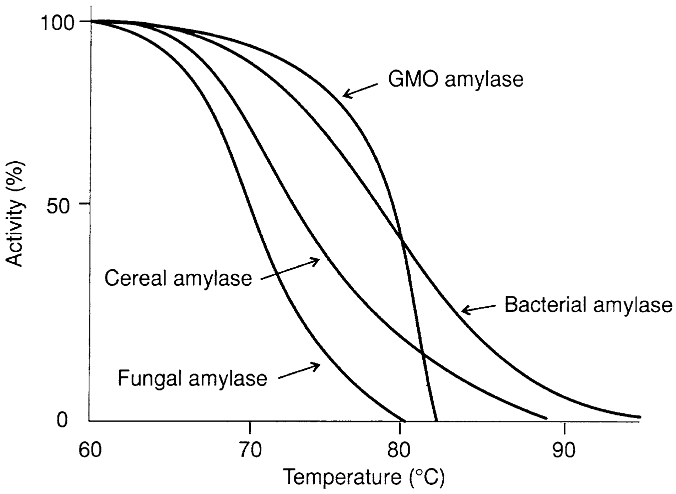

Fig. 3.6 Generalized temperature–activity curves for *alpha*-amylases from different sources

amylase will continue to produce dextrins during baking for far longer than fungal *alpha*-amylase, so that the final level of dextrins in the loaf will be higher. The major risk associated with the use of fungal amylase is at the dough processing stage, and if care is not taken to determine the optimum level of addition, or if uncontrolled delays occur during processing, sticky un-processable doughs can result.

Cereal Alpha-Amylase

The only sources of cereal *alpha*-amylase available to bakers are diastatic flours produced from malted barley and wheat. These flours contain complex enzyme cocktails which can be in some situations of great benefit. The two major components are *alpha*- and *beta*-amylases. In most but not all wheat flours there is an abundant supply of *beta*-amylase. Thus diastatic malt flour is regarded primarily as a source of cereal *alpha*-amylase. As such, cereal *alpha*-amylase is not as widely used as fungal *alpha*-amylase. Its comparatively high heat inactivation temperature would make its use at levels of activity similar to those at which fungal *alpha*-amylase is currently used impractical for sliced breads. The level of dextrins produced within the bread would almost inevitably lead to slicing difficulties of the type discussed above.

In some circumstances diastatic malt flours do offer the baker specific advantages and opportunities, for example in the manufacture of unsliced crusty goods where a high specific volume with lively movement in the oven is desirable. The crust should be well coloured and crisp but not leathery. This is primarily achieved by the correct baking technique but can be facilitated by the addition of the correct level of diastatic malt flour. In Germany any compound dough conditioner designed for the production of small crusty rolls will contain diastatic malt flour rather than fungal *alpha*-amylase.

Bacterial Alpha-Amylase

Alpha-amylases produced from bacteria are remarkable for their heat stability. They will in fact retain some of their activity throughout the baking process and can therefore continue to produce dextrins throughout the entire baking cycle and even during cooling. The result of adding even very low levels of bacterial *alpha*-amylase to doughs for the production of any sliced and some part-baked breads can be both spectacular and disastrous. The bread crumb becomes so sticky it may even become impossible to slice the loaf or conveying the impression that the product is underbaked. The only use for bacterial *alpha*-amylase in yeast-raised products is in the production of malt breads, where the incorporation of bacterial *alpha*-amylase into the recipe can produce such a loaf with a moist, sticky crumb which lasts for weeks rather than days.

Intermediate Thermal Stable Alpha-Amylase

The ability of *alpha*-amylases to retard staling, i.e. the delaying of starch retrogradation has been recognized for some time. The practical difficulty has always been that any *alpha*-amylases which demonstrated this effect were relatively heat stable, i.e. they were of cereal or bacterial origin. Such amylases produced at the same time both extended softness and excessive stickiness in the baked product due to the formation of high levels of dextrins from both the amylose and amylopectin fractions of the starch in the latter stages of baking. If it were possible to fractionate *alpha*-amylases from existing cereal or bacterial sources to obtain a specific temperature stability profile and a controlled range of hydrolysis products, it might be possible to modify the amylopectin in the baked loaf to inhibit or delay starch retrogradation without the risk of causing excessive stickiness in the baked loaf. Enzyme manufacturers have in fact been able to achieve this goal by producing *alpha*-amylases which have an inactivation temperature similar to that of ‘traditional’ fungal alpha-amylase but with increased activity at lower temperatures. Such amylases do not usually create problems with excessive dextrin formation. In the past this had been achieved by drafting specific genes into bacteria to create the required result. Sometimes referred to as maltogenic amylases, the resulting *alpha*-amylase preparations do not contain enzymes which are themselves novel, nor do they contain genetically modified material. They do, however, have specific temperature stability profiles and produce a controlled range of break-down products from amylopectin, such that when used at low levels they are able to enhance soft-eating shelf life without creating gumminess. Because of their low level of use they have no detrimental effects on the dough during processing.

In practice the great advantage of these enzymes compared to traditional crumb-softening agents, such as distilled monoglycerides, is that they extend the soft-eating shelf life for longer, i.e. they show a great advantage over the period of 3–6 days post-baking compared with monoglycerides, and are at least as good in the first 3 days. A significant further advantage is that this softness is not accompanied by either weakening or drying out of the crumb.

Hemicellulases/Xylanases

Hemicellulases are usually derived from fungal sources or bacterial sources (Kornbrust et al. 2012). The function in their parent organisms is to break down plant cell wall material ultimately into its component sugars, mainly xylose and arabinose, to provide an energy source. The endosperm of wheat from which white flour is produced consists mainly of starch, protein and lipid (see also Chap. 11). It is subdivided in the grain into small cells, the cell wall material being composed of a complex mixture of long-chain molecules based primarily on the sugar xylose. There are a number of arabinose side chains, and in some cases the chains may be cross-linked via these arabinose sugars. In a limited number of molecules there is a direct bond between some of the material and protein via ferulic acid. This whole group of related materials is often described as wheat pentosans and they are present in white flour at a level of about 2 % of the total flour weight, with higher levels in wholemeal flour. They have historically been divided into two groups, the soluble and the insoluble pentosans, which are present in roughly equal weights.

The significance of the pentosans in dough structure becomes apparent if one examines the distribution of water in bread dough. Although representing only 2 % of the total flour by weight (see Chap. 11), pentosans are associated with approximately 23 % of the total dough water, i.e. they bind roughly seven times their own weight in water. Their function can be briefly summarized as follows: soluble pentosans enhance baking performance whilst insoluble pentosans detract from it.

The commercially available enzymes described as hemicellulases when added to dough have the effect of modifying wheat pentosans and can have considerable beneficial effects on the characteristics of a wide range of baked goods. At the dough stage their use results in dough with enhanced handling properties, and which is more extensible, without loss in strength or increase in stickiness. It may even result in a modest increase in water absorption. The dough has significantly better proof tolerance, and enhanced baking stability and oven spring. The baked product has greater volume together with a finer cell structure (Cauvain 1985). The fine cell structure in turn yields better crumb colour, improved softness and resilience.

A number of suggestions with respect to the functionality of hemicellulases are outlined below:

- by bringing about a controlled increase in the solubility of the pentosans, the rate of diffusion of carbon dioxide through the dough liquid is slowed down and gas retention is enhanced;

- by controlled breakdown of the most complex pentosans, their ability to interfere with the formation of the gluten network of the dough is reduced;
- bonds may be broken between pentosans and protein, both increasing the available protein and reducing potential disruption to the protein network;
- The release of water into the dough system during baking lowers its viscosity and permits greater and later expansion (Al-Widyan et al. 2008).

Proteinases

This group of enzymes directly attacks protein chains, in doing so they increasingly and irreversibly weaken the gluten structure. They are more regularly used in North America than Europe to counteract the effects of 'bucky' flours, i.e. flours with elastic glutens (Kulp 1993). 'Over-strong' gluten is not a common problem in most European bakeries. To achieve any discernible effect in the processing of no-time doughs, they need to be added at high levels. On occasions they can be of use in the production of pinned-out morning goods if used in conjunction with L-cysteine.

Oxidase Enzymes

Oxidase enzymes find uses in breadmaking. Glucose oxidase reacts with the *beta* form of glucose. In the presence of oxygen, glucose oxidase catalyses the oxidation of the *beta* glucose and in doing so produces hydrogen peroxide. The ability of hydrogen peroxide to oxidise thiol groups to form disulphide bonds often forms the basis of the claims for the improving effect of glucose oxidase in breadmaking (Wiksrom and Eliasson 1998; Vemulapalli et al. 1998). However, in doughmaking systems where the availability of oxygen is restricted—usually by the yeast—then the potential impact of glucose oxidase may be limited. For this reason glucose oxidase has found limited application in no-time dough making systems. The application of sulphydryl oxidase as a bread improver has been postulated (Kulp 1993).

Lipase

Lipase enzymes have been shown to be effective in improving bread quality (Si and Hassan 1994). They have been shown to be particularly effective in the context of retarding staling (Poulson and Soe 1996). The action of the lipase is to cleave the bond between the fatty acid esters and glycerol on wheat flour lipids (Si 1997) and the monoglycerides so formed may be involved in the reduction of the rate of staling in bread, much as the addition of glycerol mono-stearate does (see Chap. 10). Some forms of lipase will react with the phospholipids and glycolipids as well as the triglycerides in the dough system. The potential for lipases to replace DATA esters and SSL has been postulated (Rittig 2005).

Asparaginase

One enzyme which has attracted interest is asparaginase. Its use is not associated with improved bread volume, crumb softening or reduced staling. It has attracted attention because of its potential to reduce the formation of acrylamide during baking with reductions as high as 95 % being claimed for some products into which the enzyme was incorporated (de Boer et al. 2005).

Transglutaminase

Transglutaminase catalyses acyl-transfer reactions including the formation of cross links between glutamine and lysine residues in proteins. Its use in baking is relatively recent and it may be used in combination with proteases to counteract reduced extensibility of the dough (Kornbrust et al. 2012). Suggested applications for transglutaminase (Poza 2002) include for the manufacture of frozen dough to deliver greater freeze-thaw stability, as a component of potassium bromate replacers, high fibre and rye breads, to improve the lift of laminated products (Gerrard et al. 2000) and to enhance the water absorption in steam breads thereby making the dough less likely to tear during expansion.

Health and Safety with Enzyme Usage

In recent years a numbers of concerns have been raised regarding the safety of use of enzymes in the bakery. These concerns are centred on the possible allergenicity of the materials for people working in manufacturing through exposure to dust in the atmosphere which may contain enzyme active materials. In most bakeries steps are regularly taken to reduce the presence of dust in the working atmosphere and the move in some bakeries to use liquid rather than powdered improvers (see below) is also contributing to the management of health and safety issues. Reductions in flour dust in the atmosphere can also be achieved by reducing or eliminating dusting flour during dough processing. There are no the safety concerns for consumers eating products manufactured with enzyme additions. Most of the enzymes which are used in the manufacture of baked goods are inactivated by the heat of the oven. Some forms of bacterial *alpha*-amylase may not be inactivated during baking but these are not generally forms which find significant use in baking and while they may bring about undesirable technological effects (e.g. excessive crumb softening) they are not considered to have potential health and safety issues.

Summary of Small Ingredients Usage

The materials which have been discussed above constitute some of the principal functional ‘small ingredients’ currently found in use in the manufacture of bread and yeast-raised fine bakers’ wares. When contemplating their use and potential benefits, it would be wise to bear in mind the following:

- their principal functions are to enhance and control the quality of baked goods;
- each one has a specific function and an optimum level of use in a particular system;
- they can only be used to best effect in carefully balanced combinations, so that each component complements the function of the others;
- they are able to compensate for minor variations and deficiencies in flour quality, and in plant and processing conditions;
- they are very definitely not intended to rescue the baker from incorrect or widely varying flour quality, from poorly developed dough during mixing, nor from inappropriate or badly maintained plant;
- above all, they are no substitute for an adequate level of understanding of the science and craft of baking, conscientiously applied by the baker using the products.

Liquid Improvers

Liquid dosing of ingredients to the mixer has been possible for many years. Indeed when first introduced the CBP was based on the delivery of the necessary ascorbic acid as a solution (Cauvain and Young 2006). Liquid-based systems used for delivering functional ingredients are also found in the manufacture of hamburger buns (see Chap. 9). The increased automation of plant bakeries and improvements in the mechanical ability to meter in dosages of small ingredients has resulted in an increase in the use of liquid feed systems. Liquid yeast feeds have been used for some time (see below) but recent developments have led to the increased use of ‘liquid’ improvers. The new liquid improvers provide all of the necessary functional ingredients which are more commonly found in the powdered improver but they are oil-based rather than soya- or wheat flour-based.

In a liquid improver the necessary oxidant, enzymes and emulsifiers are suspended in a suitable vegetable oil. Solid fat may also be present, usually in small quantities and in a finely divided crystalline form. The absence of any water in the liquid improver ensures that there is no loss of functionality from active materials such as oxidants and enzymes. The technology used to manufacture and deliver the improvers ensures uniform dispersion of the low levels of functional ingredients that are present and therefore consistency between dough batches in the bakery.

Initially the use of liquid improvers was confined to the larger plant bakeries but increasingly they are becoming available for use in smaller bakeries using smaller pack sizes. One particular advantage to be gained from using liquid improvers is a reduction of dust in the bakery and this makes a significant contribution towards better working conditions for the operatives with reduced exposure to enzyme active materials (see above).

'Clean-Label' Improvers

The concept of so-called clean-label improvers has been a recent introduction to the baking industry. The application of the term focusses on the fact that the improver does not contain ingredients which have E-number associated with them. Two points must be stressed about these improvers and their use. The first is that the term 'clean-label' has no definition in legislation and cannot therefore be used as a description on product labels.

The second point to make is that while many of the functional ingredients do not have an E-number associated with them they are cleared for use in the manufacture of bakery foods. The key functional ingredients are usually permitted enzymes which as noted above, are commonly (at the time of writing) typically considered as processing aids in many parts of the world and as such do not require declaration. There is no guarantee that this situation will continue.

Other so-called clean label ingredients may be listed by a common name rather than an E-number. The position of this approach may vary in different parts of the world. Thus acetic acid (E260) may be described as vinegar and E300 (Vitamin C) may be described as ascorbic acid. Vitamin C may be obtained from many natural plant sources including rose hips and blackcurrants. One natural source that has been suggested for use in bread so that the use of the term E300 is avoided is acerola (*Malpighia emarginata*) but its acceptance as an ingredient will inevitably be the subject of local legislative requirements—is the case with most alternative sources to E-numbers in food production.

Alternatives to E-number listed preservatives are being offered. A common approach is to use a preparation of fermented wheat flour which not only lowers dough pH but also provides preservatives via the fermentation of wheat flour with natural micro-organisms. Such products may well contribute organic acids such as propionic acid at analytically detectable levels and may well involve questions regarding the lack of declaration of such compounds on the product label.

Bakers' Yeast

The use of yeast in breadmaking has at least 6000 years of history since fermentation of bread dough is thought to have started with the ancient Egyptians. At that time dough fermentation would probably have taken place by using a mixture of natural yeast and lactic acid bacteria (naturally present in wheat and in milled flour). Bakers would save a portion of dough to seed subsequent doughs, and this method continued into the nineteenth century. In the Middle Ages (800–1500 AD), European bakers would produce a barm, a more liquid fermentation, which was often started with brewers' yeast from hops. Louis Pasteur's research aided the understanding and development of yeast cultures. Commercial bakers' yeast started with the Vienna Process in the mid-nineteenth century. The basis of this process was to introduce air and a small amount of steam into the fermentation. The development of the Vienna Process increased the yield and enabled quality to be controlled. At this time yeast was grown on grain. During 1915 (war-time in Europe) there was a shortage of grain and molasses started to be used commercially to grow yeast. By the 1950s grain as a substrate was phased out, although, today cereal is being used in areas where, for various reasons, it has become more economic so to do.

Principal Forms of Yeast

Throughout the world today, bakers' yeast is produced in various forms which meet specific requirements of climate, technology, product, methodology, transportation and storage. Bakers' yeast comes in a number of different forms including compressed, granular, cream, dried pellet, instant, encapsulated and frozen. The variations are related to the physical form of the yeast, with the main differences being in the ratio of yeast solids to moisture. Various cultures are developed which depend on the properties required for the yeast's intended use; this will be discussed later.

Compressed yeast. This form is normally supplied in blocks and wrapped in waxed paper. A dry matter content of 28–30 % is the standard for this product. In the UK, blocks are of 1 kg (2.2 lb); a 0.5 kg block is common in many other parts of the world. There is a small domestic market for 42 g (1.5 oz) blocks.

Granular yeast. This usually consists of small granules, has a dry matter content of 30–33 %, and is supplied in laminated paper or plastic bags. Because it has a far greater surface area than compressed yeast, it is more vulnerable to temperature increases which impair the quality of the yeast. Granular yeast has in the main been superseded by cream yeast but has been used in brew processes and automated feed systems in breadmaking.

Cream yeast. Cream or liquid yeast is a pumpable form of yeast which has the consistency of cream. Cream yeast generally replaces compressed at a rate of 1.5:1, although some cream yeast is marketed at a 1.7:1 replacement ratio, an important point for quality addition and costing. Also, when using cream yeast in the bakery, the extra water content should be compensated for in recipes, commonly be reducing the level of dough water.

Dried pellet yeast. This was an early form of dried yeast, produced as small beige-coloured pellets with a very low moisture content. Its advantage over compressed yeast was that, when packed (and sometimes gas flushed), it could be transported and stored more easily, at ambient temperatures, and had a longer shelf life. For use in the bakery, dried yeast needs to be reconstituted in five times its own weight of warm water. A variety of pack sizes are produced from 1 tonne packs for others to repack, through 12.5 kg (27.5 lb) packs to 20 g (0.7 oz) tins, in plastic containers and sachets. Dried pellet yeast has mainly been superseded by Instant yeast for bakery and domestic uses.

Instant yeast. This form was developed in the 1960s; it has a very low moisture content and a fine particle size. The main advantage of using instant rather than dried yeast is that the yeast can be added directly to the flour. Instant yeast is popular on the islands around the UK and for premixes for bread and pizzas. The main use is for baking in parts of the world where compressed yeast is not available or where instant yeast is considered to be more convenient.

Encapsulated yeast. This is a specialist yeast produced for premixes where its use does not necessitate prior drying of the flour. Due to its high cost, encapsulated yeast is little used today.

Frozen yeast. This can be compressed yeast which has been frozen under special conditions; it needs to be defrosted slowly for use. There is also a specialist yeast strain produced for frozen dough which has a lower moisture content than compressed but higher than instant yeast, with the appearance of instant yeast and which, although frozen, is free flowing.

Summary. The above descriptions illustrate the various physical forms and appearances of yeast. Drying, freezing and encapsulation are all methods of yeast preservation. Different cultures and growth methods have also been developed by yeast manufacturers to produce yeasts for the different baking methods and fermented products. The cultures and growth methods will affect a number of yeast performance factors, such as activity, acid tolerance, osmotolerance, temperature stability, response to mould inhibitors and shelf life. Some of these properties will be discussed later when considering the uses of yeast in baking.

Other Yeasts

Yeast sources such as brewers' and distillers' yeasts may be used for bread type production but, as they are not specifically developed for that purpose, they are unsuitable because they have low activity and would not have the particular tolerances built into specialist bread yeasts. The following are examples of other yeast products.

- *Pizza yeasts* have low activity. They are an instant type of product with added benefits for pizza production, such as shrinkage reduction.
- *Deactivated yeasts* are another instant form of yeast product with additional properties such as characteristics to replace L-cysteine to assist in the relaxation

of doughs. They have the benefit of being able to be declared as yeast on product labels and thus avoid the E-number associated with chemical reducing agents. The main effect comes from the glutathione which is present in the yeast cell itself (see above).
- *Inactive yeasts* are produced to give flavour and as a flavour carrier, in products such as potato crisps.
- *Yeast extracts* are used in food spreads and soup flavourings.

Biology of Yeast Cells

Yeasts are living organisms found naturally, living around us, in the air, on the ground and on the fruits and leaves of many plants. A common viable example of a yeast is the bloom we can observe on grapes. There are about 500 known yeast species. The scientific name for bakers' yeast is *Saccharomyces cerevisiae*, which means 'a mould which ferments the sugar in cereal (saccharo-mucus cerevisiae) to produce alcohol and carbon dioxide'.

The actions of yeast may be shown in a simplified form as follows:

$$\text{simple sugar} \Rightarrow \text{ethyl alcohol} + \text{carbon dioxide}$$

$$C_6H_{12}O_6 \Rightarrow 2C_2H_5OH + 2CO_2$$

Examining a yeast cell under a microscope will give a greater understanding of the composition and nature of yeast. The method for viewing a sample of yeast under a microscope is to disperse a small amount of yeast in water, causing the water to be slightly clouded, and then drop a spot of the liquor onto a glass slide. The drop is then covered and viewed with a 650× magnification. The individual cells will take the general form illustrated in Fig. 3.7. If individual yeast cells were placed side by side it would take approximately 1200 cells to measure 1 cm in length. Yeast is a unicellular organism (single cell) and 1 g of yeast contains around 15×10^9 cells. Individual cells will be seen to be round to oval in shape. Inside each cell are the following.

- A liquid solution of protoplasm, protein, fat and mineral matter.
- One or more dark patches called vacuoles.
- A darker spot which is the nucleus. This is where the cell's genetic information is stored as DNA which controls all the operations of the cell.

A yeast cell has 6000 different genes. Yeast is made up of chromosomes, like any living thing; there are 16 different chromosomes in yeast compared with 23 in humans. The double cell wall may have bud scars which are caused by the cell reproducing itself. There can be up to ten such scars, which would cover the cell totally, after which the cell would expire. The osmotic properties of a yeast cell are due to selective permeability of the cell wall with regard to solutions. This selectivity plays

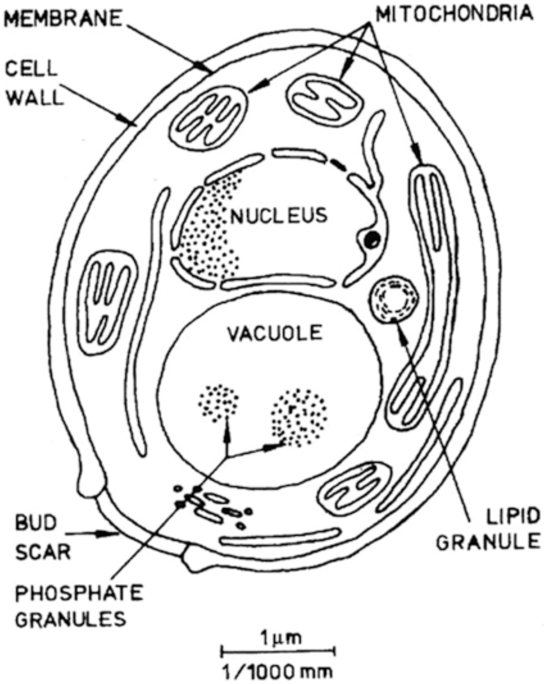

Fig. 3.7 The yeast cell

an important role in controlling the movement of nutrients into a cell. Nutrients are present in a medium in the form of ions, sugars and amino acids. The permeability of the cell wall also permits the release of alcohol and carbon dioxide from the cell during fermentation.

The commercial yeast growth process is created by encouraging reproduction, by providing the correct conditions of warm water (30 °C, 86 °F) and nutrients (sugars). Yeast is asexual and reproduces by budding. A parent cell grows a protuberance, this swells as the bud forms, a neck develops between the parent cell and the bud, and they separate. The process starts again and, in ideal conditions, a cell can reproduce itself in 20 min, so that numbers increase from 1 to 2, then to 4, to 8, to 16, and so on. If the numbers are plotted on a graph, the line would take an exponential form.

Yeast can also reproduce by sporulation. This process occurs when cells are deprived of food. Each cell will produce up to four spores which, when the cell wall shrivels away, are released into the atmosphere. Yeast cells can survive in the form of spores for extremely long periods of time and, when later brought into contact with the right conditions the yeast will return to active life. Yeast microbiologists are able to use the state of yeast sporulation to interbreed yeasts in order to produce hybrid yeast strains with specific qualities. Today, genetic engineering of yeast cells in order to confer special properties is possible but, until it is more generally accepted, yeast producers consider that it would be unwise to risk a potentially devastating drop in bread sales.

Overview of Commercial Yeast Production

The typical raw materials used for the commercial production of yeast growth are:

- molasses cane/beet;
- ammonium hydroxide;
- magnesium sulphate;
- diammonium phosphate;
- air;
- sulphuric acid/sodium carbonate (processing aids for pH control).

For yeast growth by reproduction, a carbohydrate food source is required. This could be grain, but today molasses is a cheaper form of sugar and therefore is preferred. The vitamins and minerals in molasses support yeast growth. Molasses from beet, cane or a mixture of both can be used. As molasses consists of approximately 50 % sugars, up to twice the weight of molasses is required to produce compressed yeast. Nitrogen is a major growth nutrient, which is added in the form of ammonia. Oxygen is provided in the form of filtered air.

A starter culture is grown under sterile conditions in a laboratory. A perfect, healthy cell is selected under a microscope, the culture is grown in a test tube with the required nutrients and is then transferred to flasks and larger vessels until it has grown to the required quantity for a commercial starter. The yeast culture is then constantly fed over a period of time and, as it grows and expands, it passes through approximately six stages of commercial propagators. At this stage in the production cycle the yeast cells are suspended in a large amount of water. The concentrated yeast is extracted from the water by a centrifuging process in large separators, which provides yeast in a cream form and an effluent waste. The yeast cream is cooled and can be transported in that form without further processing to large bakeries for use.

The water content of the yeast cream is further reduced by filtering, passing through a filter press or rotary vacuum filtration unit. The next process is to prepare the yeast for its final form:

- extruded for compressed yeast;
- minced for granular yeast;
- dried, either by drum drier, spray drier or fluidized bed drier for pellet or instant yeast;
- freezing of compressed or semi-dried yeast.

The yeast is packed and then transported by road, rail or ship, depending on the destination, and in frozen, chilled or ambient forms, depending on the product, customer requirements and the environment in which it will be used.

Yeast and Baking Processes

Throughout the world there are many different types of bread and processes, each of which require different performance characteristics from the yeast. To deal with such variations yeast suppliers are able to offer different strains to meet specific requirements. For example, as a result of the introduction of the CBP and other no-time dough making processes in the early 1960s, a new type of yeast became necessary. The yeast commonly used in the industry before then was too slow to gas for the new, faster processes and had an inappropriate fermentation and gassing curve. Specifically, the yeast was lacking in gas production at the critical stages of proof and during the early stages of baking. Increasing the quantity used of the existing yeast type could not rectify the situation. The two graphs shown in Fig. 3.8 illustrate the problems incurred with the existing yeast in the CBP and the effects of the new culture which was produced specifically to overcome these problems. When using the pre-1960s yeast in the CBP (Fig. 3.8a), gas production dropped at the time that the bread was about to enter the oven, resulting in little or no oven spring. In the graph for the post-1960s yeasts (Fig. 3.8b), there is no drop in gas production. Yeast for the CBP is used at a rate of 2 % of flour weight, which is more than the percentage of yeast used in long-fermentation processes.

The most favoured pH range for yeast activity is 4.5–6.0. Bread doughs are generally in the region of 5.5, so in normal breadmaking the effect of pH is not a particular consideration. Dough proof time is dramatically affected by the age and the temperature at which the yeast has been stored. The percentage difference in proof time of compressed yeast stored at 4 °C (39 °F), 10 °C (50 °F) and 15 °C (59 °F) for both 7 and 14 days is compared in Fig. 3.9, which shows how proof time to a constant height increases with the temperature at which the yeast has been stored.

Mould inhibitors, such as propionic acid and calcium propionate, have a retarding effect on yeast fermentation. Sorbic acid and its salts have a dramatic effect on yeast activity and unless used in an encapsulated form, they are not used in fermented product recipes. Depending on the type of bread product, the required shelf life and climatic conditions, the type and level of addition of inhibitors will vary. They have the effect of slowing the yeast activity and extending the proof time. It is normal for bakers to add extra yeast to the mix when using mould inhibitors. The quantity will depend on which yeast is used, since acid resistance is built into yeasts which are normally sold for use in recipes and products which contain mould inhibitors. To prevent rope occurring in bread, acetic acid or spirit vinegar (12.5 %) may be added. This will also affect yeast fermentation but to a lesser degree than mould inhibitors. Since the introduction of the 'E'-number classification in Europe, there has been a preference by bakers to use spirit vinegar, a natural product, to avoid having an E-number and giving a 'clean label' to the bread product (see below). A comparison of the effects of vinegar, calcium propionate and propionic acid on yeast activity (proof time) is shown in Fig. 3.10. Spices will also affect the activity of yeast, the quantity of spice being determined by the required flavour of the finished product. It is normal for a higher yeast level to be used in such products, and

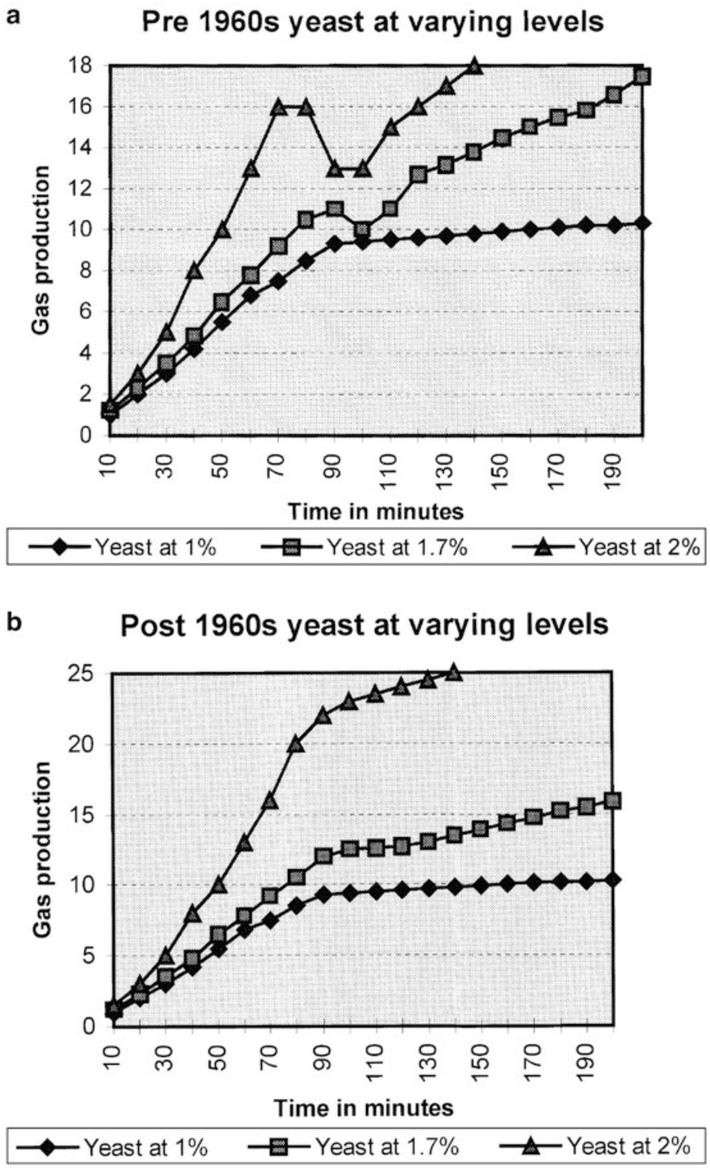

Fig. 3.8 Gas production in the CBP

bun spice is often added with fruit as late as possible in the process in order to reduce its effect on yeast activity.

As a general rule, a slower acting yeast is more robust and a faster yeast more fragile in the manufacture of frozen dough. Yeast producers do take steps to overcome specific situations by selecting appropriate cultures and changing growth

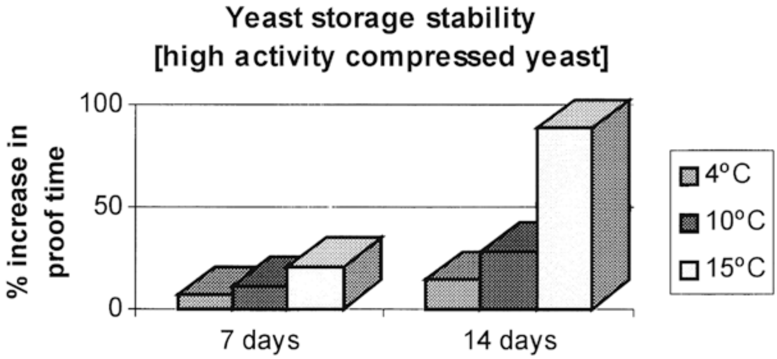

Fig. 3.9 Yeast storage stability

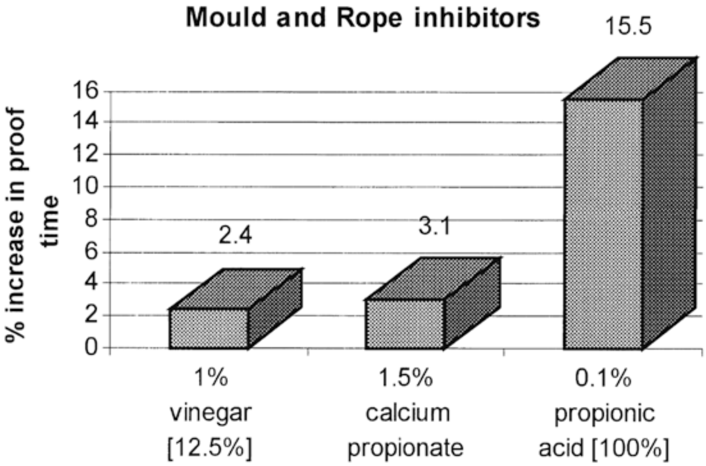

Fig. 3.10 Effect of mould and rope inhibitors on yeast activity

patterns so that the yeasts with better freeze-thaw tolerance can be offered. In Fig. 3.11 the effects of different yeasts and their performance after being frozen and stored for up to 6 months at −18 °C (0 °F) are compared. The performance of the two yeasts is very similar at between 1 and 2 months storage. If the yeast was only frozen for up to 1 month, then the faster yeast would be better, whereas when frozen for between 3 and 6 months the slower yeast appears to be better. There is a specialist frozen yeast which is produced, a free-flowing frozen yeast. Freezing of this yeast takes place during its final stage of production, and it remains frozen during delivery and until it is used. This is considered to be the best yeast for producing frozen doughs as it has built-in tolerance to freezing.

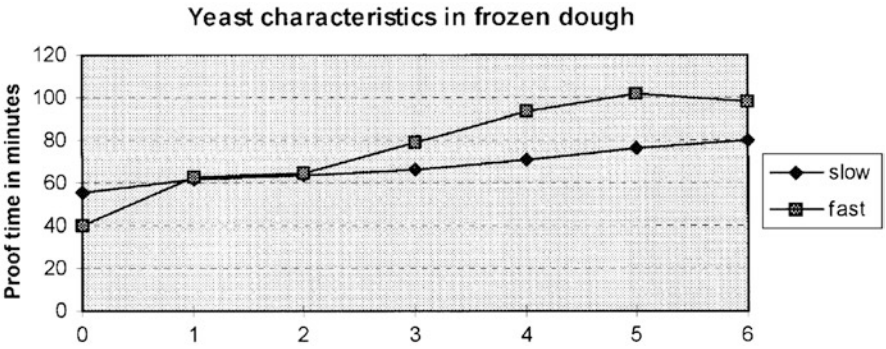

Fig. 3.11 Yeast characteristics in frozen dough

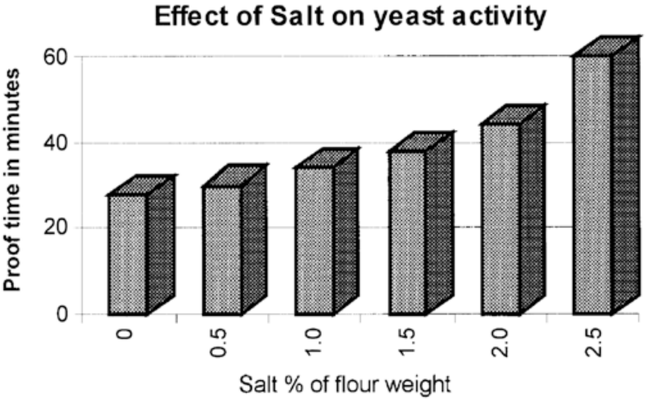

Fig. 3.12 Effect of salt on yeast activity

Salt can be used to aid the control of fermentation. There are a number of breadmaking methods, such as delayed salt (Chap. 2 and below), which allow maximum fermentation before the salt is added to check the fermentation rate. Salt is also required to assist the flavour of bread; with no salt, bread is insipid (Chap. 1). In the past the normal rate of salt addition was about 2 % of flour weight but in many parts of the world salt levels in bread are being reduced for health reasons (see below). It is common with lower salt levels to make a small reduction in yeast level to balance fermentation. The extent to which changes in osmotic pressure caused by increasing salt level affects the activity of yeast is shown in Fig. 3.12.

In the UK and many other countries, little or no sugar is used in basic breads, although specialist breads and other fermented goods, such as morning goods, may have up to 15 % sugar. Elsewhere, such as in African and Asian countries, it is not uncommon for as much as 30 % sugar to be used. Special yeasts with high sugar tolerance, for high-sugar doughs, are produced for these countries.

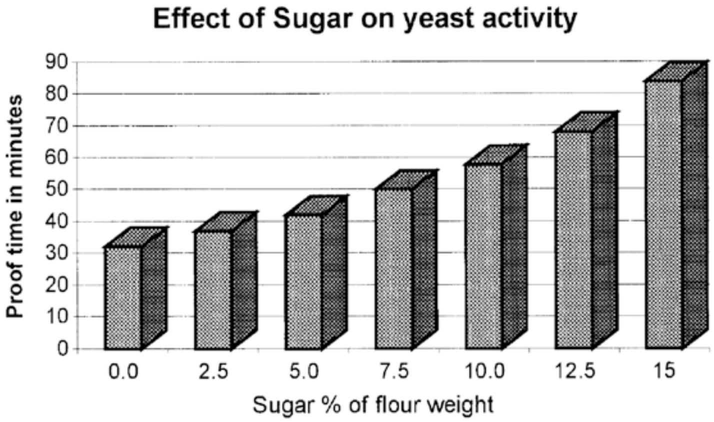

Fig. 3.13 Effect of sugar on yeast activity

Weight for weight, salt has a far more dramatic effect on yeast than sugar, as can be seen by comparing the results illustrated in Fig. 3.13 with those given in Fig. 3.12. The quantities of salt and sugar may be further adjusted in bread baking for reasons of flavour, texture and product shelf life, and so the formulation of fermented products can have a significant influence on yeast activity.

Throughout history, yeast cultures have been developed to meet market needs. The market for bakers' yeast has increased due to higher demand for fermented goods and also due to the development of automated breadmaking processes where higher yeast levels are used. The requirements for yeast are diverse, covering local to worldwide use, from home baking once a week, through hand and craft bakeries to fully automated bakeries using as much as 25 tonnes of yeast per week. The finished products vary enormously according to local culture, the availability of grain and costs. Yeasts for these different needs may be single strain, hybrid or with mixed strains and propagation profiles. Their physical condition may be liquid, dried or compressed, with storage at ambient to frozen temperatures, either sealed airtight or inexpensively wrapped. Ultimately it is necessary for the baker to choose the most suitable yeast for the process, climate and recipe, according to commercial availability.

Starter Doughs

Older methods of aerating bread dough were based on the use of portions of old dough which had fermented because of the presence of natural, wild yeasts and to a lesser extent bacteria. With the advent of the production of baker's yeast such methods became less popular, in part, because using modern baker's yeast provided a consistency of gassing performance which could not be readily achieved with ‘natural’ fermentation. However, in some parts of the world and for some products (e.g. rye bread, see Chap. 13) the principle of using starter or ‘mother doughs’ remains in practice. In recent years there has been increased interest in the starter or ‘mother doughs’ as a means of changing bread flavour and to a lesser extent providing gas production (Schunemann and Treu 2001; Calvel et al. 2001). There are many variations on the starter dough concept but the basic principle is that only flour and water are mixed together, commonly in equal proportions and left to ferment naturally for 24 h or more. The starter is added to dough mix at levels between 10 and 25 % of the flour weight depending on the degree of acidity that is required in the bread. The starter is perpetuated by retaining a portion of the original mix and replacing the mass that has been removed for baking with fresh flour and yeast. The starter dough may be based on baker’s yeast or some other suitable strain.

If the starter dough principle is used it is important that the fermentation conditions used favour the yeasts and welcome bacteria. In the latter case the main organisms naturally found in flour will be Lactic acid bacteria and it is these that are largely responsible for the acidic bite that give sour dough products their distinctive flavour. It is important that unwanted organisms are not allowed to proliferate in the starter dough otherwise off-flavours and odours may develop. In some cases the gas production potential of the starter may be impaired.

Control of the microflora in the starter culture is usually achieved through a combination of temperature and pH control. All microorganism have a combination of favoured temperature and pH conditions for growth. Conditions which favour the reproduction of one type of microorganism do not necessarily favour another and indeed may be used to suppress the activity of the undesired organism. In broad terms, yeasts prefer warmer conditions than bacteria. Thus, the functionality of lactic acid bacteria may be encouraged by using cooler fermentation or proof conditions that would normally be used for example in bulk fermentation. This difference contributes to the more acidic flavour that is often observed when dough is retarded or proved at low temperatures (see Chap. 6). There is some evidence that lactic acid bacterial activity in sours and sponges (or through cool proof) contributes to product shelf-life through an anti-fungal effect. The sponge of the sponge and dough process (see Chap. 2) differs in concept to that of the starter or mother dough in that the sponge is made, fermented and completely used in the subsequent manufacture of bread. Even if the sponge is used subsequently to make more than one dough, it is necessary to make new sponges from all fresh ingredients. Never the less as discussed previously using a sponge can introduce different flavour into the subsequent products.

Salt (Sodium Chloride)

Salt (sodium chloride) has become a common ingredient in bread products. It contributes significantly to flavour, affects the development of gluten structures, inhibits yeast fermentation (as discussed above) and contributes to the control of water activity in the in the baked product (Cauvain and Young 2008). In the manufacture of bread and other fermented products it is the development of an extensible gluten network in the dough which is an essential feature of the process. Salt affects the rate of hydration of the gluten proteins and may limit the total level of development which can be achieved. The impact of salt on gluten development has been known for some while and some breadmaking processes have evolved in which the addition of salt is delayed until the later stages of dough mixing. This approach can be particularly useful with lower protein flours and weaker gluten. Once added to the dough the ionic nature of sodium chloride ensures that it quickly gets into solution (Cauvain and Young 2008). Linko et al. (1984) discussed changes in dough rheology with increasing levels of salt addition. In general the overall effect is small compared with the dough development that comes from the energy transferred to the dough during mechanical mixing though the impact of salt on dough rheology is more noticeable with slow mixing and especially if mixing is carried out by hand.

With the current concern over levels of sodium chloride in diets around the world there has been interest in reducing the level used in breadmaking. In this context the UK baking industry has been at the forefront of change and over the last 20 years or so the level of sodium chloride present in UK baked products has fallen significantly so that by 2012 levels in bread sat at 1 g per 100 g product (Leek 2014). New targets have been set at an average of 0.9 g salt per 100 g in bread by 2017.

There has also been interest in the replacement of sodium chloride with potassium chloride but this cannot be achieved as a straight replacement. While the impact of potassium chloride on yeast activity and dough rheological properties is similar to that of the sodium salt a major disadvantage is that there is an adverse impact on flavour once the substitution levels rise beyond 10–20 %. Potassium chloride confers a distinctive ‘metallic’ taste which cannot be readily disguised from other sources and can become more pronounced when sodium chloride levels are already low. There are a number of products available which combine sodium and potassium; for example, L-salt™ which combines potassium and sodium salts in the ratio of 2:1 (Klinge Chemicals 2005). Readers are referred elsewhere for a more comprehensive discussion related to salt reduction and alternatives in bread (Cauvain 2007).

Sugars

In many parts of the world sucrose and other sugars are added to bread and other fermented products. The main impacts are on product sweetness and crust colour. They may be added in the powder or liquid form as syrups. However, as noted above, sugar does have an inhibitory effect on yeast activity and its presence also lowers water activity (Cauvain and Young 2008) which can have some effect on extending the mould-free shelf-life of the baked product. The contribution of sugar to the diet is also being called into question with calls from many quarters for sugars levels in food and drinks to be reduced (Leek 2014).

Milk Products

Milk products may be added to bread and fermented products to deliver flavour, crust colour and in some cases, to confer a yellowness to the crumb colour (Pyler and Gorton 2008). The changes which milk products bring to bread are commonly considered to be 'enrichment'. While liquid milk products may be used it is more common and convenient to use powdered forms. In some circumstances milk products may have negative effects on bread volume; these can usually be overcome by using heat treatment to inactivate the globulin proteins in milk which are the cause of the negative impact (Cauvain and Young 2001).

Malt Products

Malted wheat and barley products may be used in the manufacture of fermented products. They may come in the powder or liquid form and as diastatically active or inactive (Cauvain and Young 2009). Malt products confer flavour and colour to the baked product when used in the inactive form. Diastatically active forms contain a suite of enzymes which may impact on dough and bread quality. The two main areas of activity are related to proteolytic and amylase enzymes. Historically malt flour was used as an improver in bulk fermentation breadmaking systems to help sustain yeast activity by generating sugars from the breakdown of the starch and millers may have supplemented flour for such purposes. With no-time dough making processes the addition of malt flour can result in problems with of inward collapse of crust side walls (Cauvain and Young 2001) and slicing problems with the formation of gummy deposits (dextrins) on slicer blades. In many cases the targeted use of *alpha*-amylase enzymes from microbial sources has largely supplanted the use of enzyme-active malt products (see above).

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Chapter 4
Mixing and Dough Processing

An integral part of all breadmaking is the formation of a smooth and homogeneous dough with a developed gluten structure. As discussed in an earlier chapter, in some breadmaking processes dough development continues during resting after mixing while in others full development is achieved during the mixing process itself. Whatever the method by which dough development is achieved the next stage in bread manufacture is the subdivision of the bulk dough (dividing) and the shaping of the individual dough pieces (moulding) to conform to the requirements of the bread variety being made. Shaping may be a multi-stage operation and may involve a further resting period between moulding stages (intermediate or first proof). Once finally formed the dough pieces commonly pass on to be proved before baking.

Before the introduction of machinery, dough the world over was made by hand mixing of the ingredients and then by kneading the mixture until a dough was created. The processes of mixing, dividing and moulding can be carried out by hand; indeed this is still the case in many bakeries, for example in India where the production of loaves in Bombay is still based on hand mixing. Increasingly the operations of mixing, dividing and moulding are becoming mechanized. The purpose of this chapter is to discuss the essential elements of dough mixing and processing, to consider how they are achieved and to consider how equipment design can impact on final product quality.

Functions of Mixing

All mixing machines available today are designed to incorporate both the mixing and the kneading characteristics of the manual process. In essence mixing is simply the homogenization of the ingredients, whereas kneading is the development of the dough (gluten) structure by 'work done' after the initial mixing. In mixing machines today this 'work' is carried out by a variety of methods, each suiting the output capacity required, the type of dough required for the final product specification and its use in subsequent processing.

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Some of the basic requirements for dough mixing have been introduced in previous chapters, but it is worthwhile to summarize them again before considering the different types of mixing machines which are available and how they may or may not meet the basic requirements of dough mixing.

We can summarize mixing requirements as the following:

- To disperse uniformly the recipe ingredients;
- To encourage the dissolution and hydration of those ingredients, in particular the flour proteins;
- To contribute energy to the development of a gluten (hydrated flour protein) structure in the dough;
- To incorporate air bubbles within the dough to provide gas nuclei for the carbon dioxide generated from yeast fermentation and oxygen for oxidation and yeast activity;
- To provide a dough with suitable rheological character for subsequent processing.

While not a requirement of mixing it should be noted that all types of mechanical mixing action will result in the transfer of heat to the dough, the amount of heat which is transferred is directly related to the mixing action and total energy imparted during the mixing time. Not all of the energy will be transferred to the dough as some will be lost to the metal of the mixer and a little to the surrounding atmosphere. Some of the heat absorbed by the metal of the mixing machine will subsequently be lost to the surrounding atmosphere but in many commercial bakeries where dough mixing machinery is running for long periods of time the amount of heat transferred to the dough quickly reaches what is in effect a ‘steady state’. This in turn means that most of the energy of mixing translates to heat input to the dough.

Types of Mixer

Mixing machines vary widely from those that virtually mimic a hand mixing action, to high-speed machines which are able to work the mix intensively to the required dough condition within a few minutes. Many mixing machines still work the dough as originally done by hand through a series of compressing and stretching operations (kneading), while others use higher speed folding coupled with intensive mechanical shear to impart the necessary work to the dough.

In many mixing processes the velocity of the dough being flung around within the mixing chamber is used to incorporate the full volume of ingredients into the mix and to impart energy to the dough from the mixing tool during kneading. Where mixing systems rely more heavily on this effect they tend to require a higher minimum mixing capacity for a given mixing chamber capacity in order to remain efficient because the mixing tool does not come into intimate contact with every ingredient molecule. This practical effect tends to limit the higher-speed mixers to the large-scale bakeries where bread plants are running at near maximum capacities and variations in batch mixing sizes are not common. In smaller-scale production greater versatility of batch size may be required from the mixers, and so lower mixing speeds and more intimate contact between the mixing tool and dough are an advantage.

In order to describe the most common variants of mixing machines and their applications, they may be divided into six common groupings (the first four being based on batch mixing) as follows:

- Chorleywood Bread Process (CBP) compatible, where the essential features are high mixing speeds and high-energy input, to develop the dough rapidly, and with control of the mixer atmosphere;
- High speed and twin spiral, where a high level of work can be input to the dough in a short time but atmospheric control is usually lacking;
- Spiral, in which a spiral-shaped mixing tool rotates on a vertical axis;
- Horizontal bar mixers in which the mixing tools rotate on a horizontal axis and sweep the developing dough against the sides of the mixer;
- Low speed, where mixing is carried out over an extended period of time;
- Continuous where the dough leaves the mixer in a continuous flow.

CBP-Compatible Mixers

The essential features of the CBP have been described in Chap. 2 and elsewhere (Cauvain and Young 2006a). For a mixer to be compatible with the CBP it must be capable of delivering a fixed amount of energy in a short space of time, usually 2–5 min. The required energy will vary according to the properties of the flour and the product being made. In the UK energy levels of about 11 Wh/kg (5 Wh/lb) of dough in the mixer are common, while in other parts of the world or with products such as breads in the USA, this may rise to as much as 20 Wh/kg (9 Wh/lb) of dough (Tweedy of Burnley 1982). Whatever the absolute energy level to be used, the short mixing time is very important in achieving the correct dough development and bubble structure formation in the dough.

Because of the CBP requirements, motor power levels will be large. The most common CBP-compatible mixers consist of a powerful vertically mounted motor drive, directly coupled through a belt system to a mixing blade (impeller) mounted vertically in a fixed bowl or tub (Fig. 4.1). The high velocity of dough being flung off the impeller sweeps the bowl walls clean during mixing and subsequent mechanical development. The mixing bowl is mounted on horizontal pivots and is capable of being tilted to receive ingredients and for dough discharge into a trough (Fig. 4.2). Other systems are available using a horizontal motor drive directly coupled to the mixing tool via a straight coupling or gearbox. Some versions have additional motor-driven bowl scrapers to encourage dough into the mixing area. In these mixers discharge is through an end door or through a bottom-mounted gate.

There are many variations to the design of the impeller blades used within CBP-compatible mixers. The primary function of the impeller is to aid dough development and it does this by interaction with a series of projections fitted on the inside of the bowl. As the dough impact on the bowl wall the projections turn it back

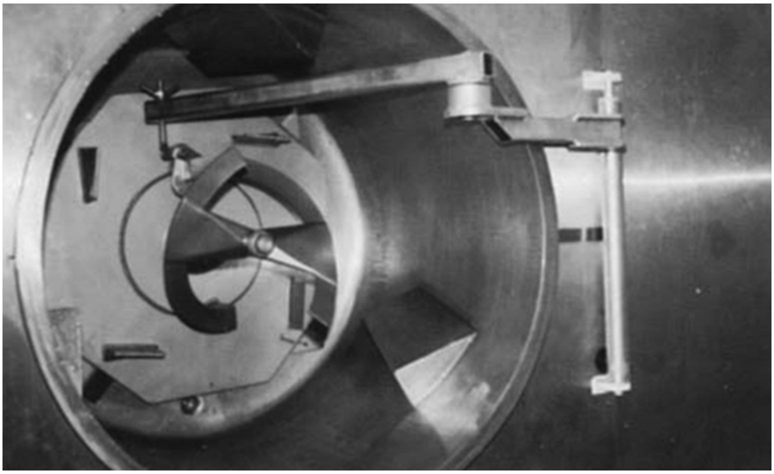

Fig. 4.1 Mixing chamber for CBP-compatible mixer shown with tool for removing mixing blade (courtesy Benier bv)

Fig. 4.2 Mixer and ingredient feed system for CBP doughs (courtesy Baker Perkins)

to towards the impeller blade and gravity pulls the dough downwards. In addition to this tumbling action the action of the impeller blades sweeping past the internal projections stretches the part of the dough which is momentarily trapped in the narrow space between projection and impeller plate. The number and positioning of the internal projections can have an effect on the rate of energy transfer during mixing, as can the design of the impeller or impact plate. However, measurements of gas bubble populations and bread crumb cell structure suggest that the design of the impeller has a limited effect on these dough and bread properties (Cauvain 1999).

In the production of US style-breads, where fine cell structures and higher energy inputs are required to achieve optimum dough development, CBP-compatible mixers may be fitted with a cooling jacket to maintain control of final dough temperatures (French and Fisher 1981). However, it should be remembered that as the result the mixing action in Tweedy-type mixers that the dough mass contact with the sides of the bowl is limited in the 2–5 min of mixing time and so the amount of heat that can be removed from the dough during mixing is relatively limited.

Additional features of CBP-compatible mixers include:

- Measurement of energy input to permit mixing to a defined dough energy input rather than time (though a time-out facility may be fitted to ensure that plant output is monitored);
- Automatic control of the mixing cycle and changes in mixer headspace pressure;
- Automatic ingredient feed systems;
- Programmable logic controls integrated with a preselectable recipe menu and fault diagnostic system;
- An integrated washing and cleaning system.

The most common applications of CBP-compatible mixers are the high-capacity production of bread and rolls with production lines rated for continuous 24 h output. Typical mixing plants are available as single or duplex mixers with outputs from 2000 (single mixer) to 10,000 (larger twin mixers) kg dough/h (900–4500 lb/h). More bread is produced from dough mixed with CBP-compatible mixers in the UK than from any other mixing system, and they can be found in use in many other countries around the world, including Australia, New Zealand, South Africa, India, the USA, Germany, Spain, France and Greece. A wide range of bread products are manufactured with CBP-compatible mixers and include pan breads, rolls and hamburger buns (Cauvain and Young 2006a).

Mixing Under Pressure and Vacuum with CBP-Compatible Mixers

In many CBP-compatible mixers control of the headspace atmosphere is incorporated into the mixing arrangements. In its ‘classic’ form this consisted of a vacuum pump capable of reducing the headspace pressure to 0.5 bar (15 in of mercury). This arrangement permitted the addition of extra water to the dough, provided a denser dough at the end of mixing (Cauvain and Young 2006a) and reduced variations in dough divider weights. It also yielded a finer, more uniform cell structure, a softer crumb and a brighter crumb appearance. The application of partial vacuum can continue throughout the mixing period or may be delayed to the latter part of the mixing cycle. The advantages in delaying the application of partial vacuum are that better oxidation via ascorbic acid can be achieved in the early part of the mixing cycle before oxygen levels are depleted by gas volume reduction and yeast activity.

The oxygen dependency of ascorbic acid and its contribution to dough development has been discussed above. With the loss of potassium bromate as a permitted oxidizing agent in UK breadmaking (and elsewhere), the relationship between mixer headspace atmosphere and ascorbic acid became more critical. If ascorbic acid was the sole oxidant and the whole of the (short) dough mixing cycle was carried out under a partial vacuum the resultant bread lacked volume and had a coarse crumb cell structure and a dark coloured crumb. Delaying the introduction of partial vacuum to the later stages of mixing brought about some improvements in final product quality. However, a key requirement of the successful application of partial vacuum was that the dough should be subjected to the reduced pressure setting for a reasonable period of time during mixing. In other words, it was not simply a case of achieving the final reduced pressure level at the end of the mixing cycle, the reduced pressure had to be achieved and held for some time before mixing was completed. Typically the length of time required for the reduced pressure to be effective in delivering the required cell structure in the final product was in the order of 30 s. Thus, in a 3 or 4 min mixing cycle the efficiency of the vacuum pump in lowering the mixer headspace pressure to the required level becomes critical. In practice these requirements tended to limit the introduction of pressure reduction to about half-way through the mixing cycle and deficiencies in bread quality could still arise.

In response to the deficiencies in product quality of some breads produced using the CBP with only ascorbic acid, an alternative new CBP-compatible mixer was developed in which mixer headspace pressures could be varied both above and below atmospheric (APV Corporation Ltd 1992). This mixer is most commonly referred to as a ‘pressure-vacuum’ mixer. It utilizes many of the basic principles of the CBP-compatible based on the original design of Tweedy mixer but has a mixer bowl which is capable of withstanding positive pressures as well as operating at negative pressures. An inlet device allows for the movement of air through the mixer which ensures improved ascorbic acid-assisted oxidation. In some versions of the mixer the running speed of the motor may be varied. The mixer headspace pressure may be changed during the mixing cycle and so it is possible to start at one mixer headspace pressure and move sequentially to another. This arrangement is similar to the delayed application of partial vacuum commonly used with CBP-compatible mixer but differs in that pressures greater than atmospheric may be applied.

The versatility of control of mixer headspace atmosphere pressures with the pressure-vacuum mixer provides a mixer capable of producing fine-structured sandwich breads or open-structured French baguette simply by varying the pressure combinations applied during the mixing cycle (Cauvain 1994, 1995). As discussed above, it is necessary for the dough to be subjected to the pre-set pressure for a short period of time before mixing is completed. This is true whether the required mixing pressure is above or below atmospheric pressure. The changes introduced in the pressure-vacuum mixers have a direct impact on the gas bubble populations which are formed in the dough during mixing and in doing so directly impact the final cell structure in the baked product. The control of mixing conditions is critical because of the strong link between crumb cell structure and the softness and eating qualities in bread and fermented products (Cauvain 2004). The versatility of the pressure-vacuum mixer with its ability to more closely control the final crumb structure provides unique opportunities for bakers.

Oxygen-Enrichment of the Mixer Headspace with CBP-Compatible Mixers

The critical relationship between oxygen and ascorbic acid in the development of a suitable gluten structure in modern bread dough has been discussed above. In the case of the pressure-vacuum mixer pressures greater than atmospheric can be used to deliver more oxygen to the dough via increased air flow. An earlier alternative to the use of pressure to deliver increased oxygen levels to the dough during mixing was developed for CBP-compatible mixers based on oxygen-enrichment of the gases in the mixer headspace. This method of mixing was based on the study of the role of gases in the CBP by Chamberlain and Collins (1979) who showed that a mixture of 60 % oxygen and 40 % nitrogen in the mixer headspace would yield bread with improved volume and finer cell structure than could be obtained from doughs mixed in air. The other advantage of using an oxygen-enriched gaseous mixture was that the application of partial vacuum was not required to yield fine and uniform cell structure in the product.

The concept of oxygen-enrichment of the mixer headspace was developed to a commercial-scale based on a mixture of oxygen and air rather than oxygen and nitrogen. All of the necessary safety features were developed and applied in the manufacturing environment. The quality of the bread was considered acceptable but the process was discontinued in the UK because of concerns about the ‘legality’ of the process. The concerns revolved around whether the use of oxygen in this way determined that it should be classed as an ‘additive’ and rather than be caught up in a protracted and potentially expensive investigation the commercial bakeries concerned stopped using the concept. An alternative to using an oxygen enriched atmosphere could be achieved by blowing air through the mixer but the cell structure of the final product was not as fine as that achieved with oxygen enrichment. With the development of the pressure-vacuum mixers interest in oxygen enriched atmospheres in mixers diminished.

High-Speed and Twin-Spiral Mixers

This category includes the widest variation in mixing design. It may be defined by the single ability of the mixer to impart a high level of mechanical work to the dough in a short period of time. Effectively, any mixer which can fully develop a dough within 5 min could be termed a high-speed mixer but the absence (mostly) of mixer headspace control separates this category of mixers from the CBP-compatible types.

Mixing criteria vary from one mixer design to another. Mixing to fixed time is the most common element, but some manufacturers offer alternative mixing controls based on dough temperature, energy consumption or even a combination of two different criteria (e.g. mix for y min unless dough temperature exceeds x°C). Not all high-speed mixers achieve mechanical dough development through an intense shearing and shearing action as experienced in most fixed-bowl machines with high-speed impellers. Manufacturers of twin-spiral and so-called 'Wendal' mixing systems (Fig. 4.3) claim that mechanical development is achieved through the stretching and folding action induced during the kneading stage (see Fig. 4.4). Whatever the mechanism of dough development, the absence of mixer headspace atmosphere control in this category of mixers does not permit as wide a range of cell structures in the final product as can be obtained in the CBP-compatible style. The absence, in some cases, of mixing to a fixed energy may lead to variations in the final bread qualities.

Fig. 4.3 Wendal kneader (courtesy Dierkes and Sohne Gmbh)

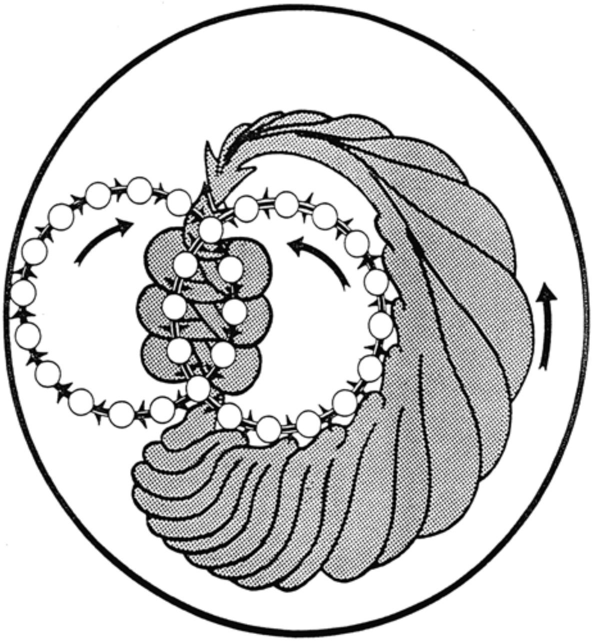

Fig. 4.4 Wendal kneading action (courtesy Dierkes and Sohne Gmbh)

High-speed mixers come in a multiplicity of designs, many of which were not originally born from the needs of bread manufacture. Usually the bowl or mixing tub is static during mixing. In some versions the mixing bowl is removable to enable dough to be handled across the bakery, reducing the time for the dough to be transferred from one container to another. Twin spiral mixers are a development of the single spiral mixer where the dough is brought by the rotation of the driven bowl through two mixing tools, instead of one as seen on conventional single spiral mixers. A variation of this form, which is able to generate a very high intensity of mixing action, is where the dough is drawn by the action and design of the mixing tool between two high-speed integrated tools (e.g. Wendal). Most twin-spiral mixers have removable bowls, with the bowl driven during the mixing cycle and offer two speeds for mixing (slow) and kneading (fast). High-speed mixer capacities vary from 50 to 300 kg dough/h (22–140 lb/h) but most commonly dough outputs from such mixing arrangements are 1500–3000 kg dough/h (680–1350 lb/h).

Spiral Mixers

The spiral mixer in its many variations has become the most common batch mixer throughout the baking industry with mix sizes ranging from 10 to 300 kg (4–140 lb). Production capacities may rise to 2300 kg/h (1000 lb/h), or higher when spiral

Fig. 4.5 Spiral mixer (courtesy Dierkes and Sohne Gmbh)

mixers are combined into integrated mixing systems. A basic definition for this ubiquitous type is that the mixing machine is equipped with a spiral-shaped mixing tool (Fig. 4.5) rotating on a vertical axis against the inner circumference of a bowl which is also rotating about its vertical axis. The mixing criteria are usually based on mixing time with most mixers having two speeds, slow for mixing and fast for kneading. Some mixers are available with control criteria based on dough temperature or energy consumption, and one example is available with a form of dough viscosity measurement.

The speed of the fast mixing setting on spiral mixers in this category is typically slower than that typically produced by high-speed or CBP-compatible mixers, and energy input into the dough is much less, typically half that required for CBP in 5 min of mixing. As a result of lower energy inputs, the temperature rises experienced during spiral mixing are lower than with high-speed and CBP-compatible types.

The rotation of the mixing tool with respect to bowl rotation and the ratio of spiral blade diameter to bowl diameter vary from one manufacturer to another. Mixing tool designs and speeds also vary, although the basic mixing action is for the mixing blade to generate a downward force on the dough. Ingredients are mixed and later the dough is kneaded by the action of the spiral blade stretching the dough against the bowl wall and base and by folding the dough on itself repeatedly. The intensity of the mixing action varies with the different velocities and surface areas of different spiral mixers. In each case the rotation of the bowl is used to re-circulate the mix/dough back to the mixing tool for more work. Many claims are made with respect to the advantages of different designs to ensure that all of the dough is mixed in the most beneficial way. Some manufacturers provide a large, high-powered mixing tool which sweeps an area the diameter of which is greater than the bowl radius in order to eliminate 'dead spots' in the centre of the bowl. Others engineer central posts to guide the dough into a smaller mixing tool. These central posts are also engineered to achieve different effects on dough development; some are large central spigots which increase the effective kneading surface, while others are blade-like to generate a shearing action between them and the mixing tool. All such designs may have advantages of one type or another. The test of the complete mixing system, however, depends on how well the dough is homogenized, its structure, the time taken to accomplish mixing and the energy lost as heat during mixing. The variety of dough structures required from various ingredients for various bread products also means that there is no perfect design for all doughs. In reality, since most spiral mixers come equipped with two speeds, the ratio of the slow to fast periods is varied to accommodate the different kneading intensities required. Typically the slow period is extended for 'weaker' doughs with a corresponding reduction in the length of the fast period.

Reference has already been made to the lower energy input from spiral mixers compared with CBP-compatible types, and the effect that this will have on dough development has been discussed in an earlier chapter. There are two other important differences which require comment, and both are related to gas occlusion in the dough during spiral mixing. Compared with CBP-compatible mixers, spiral mixers are more effective in occluding air into the dough during the mixing cycle. A comparison of typical gas occlusion values is given in Table 4.1. The occlusion of a greater volume of air during spiral mixing increases the quantity of oxygen available for ascorbic acid conversion, so that the potential oxidizing effects are greater. However, the mixing action involved in a typical spiral mixer generates a gas bubble size range which is considerably greater, and with a larger 'average' size than would occur with CBP-compatible mixers (see below). These two factors, perhaps more than any others, explain why spiral mixers have become so commonly used in the production of breads with an open cell structure, such as French baguette.

Table 4.1 Examples of gas occlusion in different mixers

Mixer type	Proportion of gas by volume (%)
Spiral	12–15
CBP-compatible	8
CBP + partial vacuum	4
CBP + pressure	20+
Low speed	3–5

Dough handling for spiral mixers is typically either by hand from machines where the bowl is fixed, or by a bowl discharge system, usually tipping the bowl above a hopper for subsequent handling. In the latter case the bowl is usually removable from the machine. The rotating bowl is particularly suited to automated scraping of sticky doughs from its walls during discharge by means of tipping. There are variations on this theme with examples where the whole mixer is tipped up for discharging, where the bowl discharges through an orifice in its base to the elevating systems and where the bowl and its drive are attached to a high tip which is an integral part of the machine. The flexibility provided by the removable but interchangeable mixing bowl equips this style of mixer for use in automated mixing systems incorporating many ingredient stations, mixing stations, emptying stations and resting/fermentation stations. Earlier designs for such operations were based on the so-called ‘carousel’ arrangement where several bowls rotate in a frame around a central axis, moving from one station to another. More recent systems incorporating large numbers of resting/fermentation stations are based on linear arrangements where the bowl is handled from rails (mounted above or below) between stations positioned either side of the rail system.

Horizontal Mixers

The largest high-speed mixers can be found in the USA and Japan with batch capacities up to 1000 kg (450 lb). Such machines are used on high-output production lines where very highly developed doughs are produced on horizontal or ‘Z-blade’ mixers. This type of mixer usually consists of twin horizontally turning mixing tools contra-rotating in a drum-shaped mixing tub which can be tilted about its horizontal axis for discharging. Dough development is considered to be delivered by sweeping dough against the side of the bowl and the stretching and folding actions imparted by the contra-rotating blades. The energy imparted to the dough during mixing is so great that pre-cooling of the ingredients or additional cooling from a refrigerated mixer jacket are required to maintain the required final dough temperatures. The efficiency of the cooing jacket is aided by the long periods of contact of the dough with the sides of the mixing chamber. Typical mixing times are in the order of 10–15 min though they may be extended to 20 min in some cases.

Low-Speed Mixers

The first development of mixing machines for bread doughs were what we would now describe as slow-mixing systems. This was due to the requirement to mimic the hand-mixing process, rather than to a limitation of engineering capability. Low-speed mixers are still used today as they are still the most appropriate mixing system for some types of dough and products, e.g. baguette and ciabatta. The most common slow-mixing systems are the twin reciprocating arm mixer and the oblique axis fork mixer or ‘wishbone’, and less commonly the single-arm reciprocating mixer. All feature a gentle mixing action and consequently a low rate of work input. The low level of mechanical development and comparatively low rate of air occlusion are the main reasons why today these mixers are most commonly linked with bulk fermentation processes, as they were before the advent of mechanically and chemically developed doughs.

Twin-Arm Mixers

In a direct mimic of hand mixing, two linked arms are driven in a symmetrical reciprocating action such that the mixing tools mounted on the end of the arms fold ingredients from the centre to the outside of the mixing bowl during mixing (Fig. 4.6). The arms also lift, stretch and fold the dough during kneading. Ingredients are returned to the mixing tools by rotation of the mixing bowl, which also aids stretching during kneading. Unlike other mixing systems very little kneading takes place

Fig. 4.6 Twin-arm mixer (courtesy Artofex)

against the bowl wall and the mixer usually has only one speed. Typical mixing times are between 15 and 25 min and the mixing time is dependent on machine capacity, ingredient specification and the dough character required. Capacities for this type of mixer typically range from 50 to 350 kg (22–160 lb) dough weight. This style of mixer is particularly effective for the incorporation of delicate fruits without damage or the mixing of doughs with a weak or delicate gluten structure.

Oblique-Axis Fork Mixers

This type of mixer has a single mixing tool shaped like a wishbone, with profiled ends, mounted obliquely to the axis of the bowl (Fig. 4.7). The mixing bowl typically has a centre boss such that the tool action takes place between the boss and the bowl wall. Most mixers of this type have no bowl drive but allow the bowl to rotate against a friction clutch, the drive force being provided by the action of the tool against the outer bowl wall as the tool rotates. Adjustment of the clutch therefore

Fig. 4.7 Oblique-axis or fork-type mixer (courtesy VMI)

has a direct influence on the kneading characteristics of the mixer. If a mixer of this type has a driven bowl it will have a fixed kneading characteristic. Initial mixing is a function of folding the ingredients into each other as the mixing tool rotates. Later kneading is with respect to the squeezing action between the mixing tool and the bowl. The profiled ends of the tool act as plough shares to incorporate dough from between the forks into the kneading zone. Typical mixing times are between 15 and 20 min. Capacities for this type of mixer typically range from 50 to 350 kg (22–160 lb) dough weight. Larger mixers are available with removable bowls.

Continuous Mixers

These have been developed to meet the needs of dough make-up processes that are particularly sensitive to changes in dough consistency and density arising from variations in processing time between mixer and divider which occur with some batch mixing processes. Where bakers produce large quantities of dough to a narrow specification the continuous mixer also offers advantages in terms of operator requirements because some versions can run continuously without operator supervision. The most common form of continuous mixer in use for bread production today is the two-stage mixing system. As with all such systems it is the integration of an ingredient feed system with a flow-through mixing system. Dry ingredients are stored locally to the mixer, in bins which can be discharged at a controlled rate. The reader will understand that proper control over the discharge rate is essential, and so some systems continuously check this by placing the storage bins on weighing load cells so that the ‘loss in weight rate’ can be checked against the required recipe. Discharge is typically achieved by properly sized spiral or screw conveyors which have variable-speed drives to enable the rate of loss in weight to be adjusted by the control system. Some systems feed directly from the dry ingredient bins to the primary mixing chamber, while others feed into a transport auger which conveys and blends the different dry ingredients. At the primary mixing chamber, water is added along with other liquid ingredients such as cream yeast or pumpable (fluid) fats. If fresh yeast is used it is often added after the primary mixing chamber. Various designs of primary mixing chambers are offered by manufacturers. Important aspects of this part of the system are that the ingredients are uniformly distributed and the mix achieves homogeneity. The primary mixing chamber design is such that the mix is ‘pumped’ from this chamber into the secondary mixing or kneading chamber.

The common kneading action at this stage is similar to that of a horizontal mixer described earlier. However, the mixing tool is placed in a tightly configured trough with an opening at the discharge end, so that the mix and dough fed into one end of the kneading trough displace fully developed dough at the discharge end by virtue of the fact that the total dough quantity is greater and the level of dough in the trough is higher. The work done during kneading is a function of the flow rate and tool speed. Some manufacturers include variable-speed tool drives in order to adjust the dough development with respect to recipe, throughput and product requirements. While variations in mixing speeds in order to match changes in plant speeds can be readily accomplished, this may lead to variations in dough development unless a compensatory change can be made. Such a change could be a variation in the speed of the mixing tool, such that more or less work is imparted to the dough as the throughput rate changes. An adjustment in ingredient temperatures or the effectiveness of the cooling system might also be required. Such considerations explain why continuous mixers are best suited to production lines running dedicated or very limited product ranges. The kneading trough is commonly provided with a refrigerated cooling jacket to maintain and control dough temperature during the mixing process. The use of an integrated control system is essential with this type of mixing plant, and so a computer or PLC-based system is used to enable the operator to choose different recipes and mixing parameters without having to set up complex machine functions.

It is necessary for the system to be full of ingredients and product for it to work effectively and efficiently. Hence, some product is lost at the beginning and end of production shifts, if the mixer is stopped, during product changes and during cleaning periods. Some of the potential drawbacks of continuous mix systems have been the difficulties associated with reconciling raw material in and dough product out, i.e. yield, and potential losses from plant interruptions. The creation of bubble structure and dough development during mixing follow similar lines to those discussed previously for batch mixers and no-time doughs. In general bubble distributions from continuous mixers are uniform. Some opportunities exist for modifying mixer atmospheres, but the relatively ‘open’ nature of the mixer limits the potential for oxygen enrichment. Because of these practical considerations the range of bread structures which may be created during continuous mixing are mostly limited. There have been attempts to adapt continuous mixing to permit the control of pressure in the mixing chamber. In the COVAD project (Alava et al. 2005) a prototype continuous mixer was developed to provide sections capable of operating at both above and below atmospheric pressure and thus was able to achieve some of the advantages of the batch pressure-vacuum mixer, namely to increase ascorbic-acid assisted oxidation and to provide a range of cell structures in the final product.

Control of Dough Temperature and Energy Transfer

Control of Dough Temperature

During mixing the temperature of the mixture of ingredients which constitute the developing dough begins to rise as a direct consequence of energy being transferred to the dough. It is important for bakers to produce dough with a consistent final dough temperature in order to ensure uniform processing after mixing and to optimise final product quality. The heat rise which typically occurs during mixing is compensated for through the adjustment of ingredient temperatures, most notably the temperature of the water. The principles which can be used for calculating the required water temperature for a given final dough temperature and a given mixer are discussed in Chap. 2.

The availability of sufficient chilled water is critical to the delivery of a dough at a consistent temperature at the end of mixing. This means that there must be a sufficient capacity of chilled water and the refrigeration equipment must have the capability of delivering the chilled water at the required rate. The calculation of the required capacity of the refrigeration plant is a relatively straightforward but should be based on realistic conditions which take into account flour and water temperatures in the warmest conditions likely to be experienced in the bakery. In some cases the mixing environment will dictate that the temperature of the dough water required will be 0 °C or even lower. Clearly this is not realistic for water which at such temperatures will form as ice. It is possible to use ice to aid the control of dough temperature, not least because of the high latent heat required to convert ice to water. The addition of ice may have an inhibitory effect on hydration of the gluten-forming proteins, never the less the cooling advantages to be gained cannot be overlooked in those situations where temperature control could not otherwise be achieved. In practice, the use of and ice slush, a mixture of finely divided ice and water is possible. An alternative to the ice slush is the use of a chilled salt solution which has the advantage that the solution will remain liquid a few degrees below zero (32 °F) because the salt depresses the freezing point of the water. A disadvantage of using a salt solution in this way is that variations in the level of liquid addition to compensate for any variations in the water absorption capacity of the flour or the dough handling requirement of the plant result in small variations in the level of salt in the dough which, in turn, leads to potential variations in yeast activity. A common practice is to deliver both chilled salt solution and chilled water to the mixer so that the salt level remains consistent. Such an approach requires sufficient refrigeration capacity to ensure that the requirement for chilled water can be met.

Other proposed means of combating the heat rise during mixing have been the chilling of the flour and the use of carbon dioxide snow. The problems and expenses associated with the chilling of flour are considerable and are not really practicable. The delivery of carbon dioxide snow directly to the mixer does have significant potential for compensating for the heat rise of mixing. However, the use of carbon dioxide in this way will impact on the gas composition in the mixer headspace. In particular it will increase the carbon dioxide concentration and most critically reduce the oxygen (from the air) concentration with the potential for limiting the effectiveness of ascorbic acid additions.

Energy Transfer

Mixer design and operating speed have significant impacts on the transfer of energy to the dough during mixing. A key element is the interaction between the mixing tool and the dough as it moves around the mixing bowl. In most mixing actions the dough is squeezed through a relatively narrow space which stretches the dough in a manner similar to that achieved with hand mixing. If the mixing speed is low then the heat which is transferred to the dough may quickly dissipate and there may be no sign of a rise in dough temperature. As the speed of mixing increases then there is less opportunity for the energy to be dissipated and it is stored as heat in the dough. This is commonly the case with all mechanical mixers. In some cases the rate of transfer of energy to the dough is increased through the use of internal projections in the mixing bowl while in others the mixing tools are designed to 'screw' the dough more vigorously. A number of such variations have been discussed above. In all cases it appears that the basic principle illustrated in Fig. 2.5 applies, namely that an increase in the rate at which energy is transferred to the dough will give increased dough gas retention for a given work input. In other words, the faster that the dough is mixed (the lower limit seems to be around 90 to 120 s) and therefore the more rapid the development of the dough the greater will be the bread volume for the optimum work input of the flour being used.

Dough Transfer Systems

As discussed above, mixing systems can discharge dough in a variety of ways to the next dough processing stage. The most common is batch handling the full mixing capacity of the mixer using either a mobile bowl or receiving dough tub (trough) from the mixer to a receiving hopper feeding the dough divider or extruder. Alternative mixing systems provide for a continuous flow of dough either directly to the divider or via a conveyor system. Some equipment combinations require the dough to be pre-divided prior to the divider to allow a divider hopper of smaller capacity than that of the batch mixer.

Ideally all such transfer equipment should be minimized by choosing compatible mixing and dough processing batch equipment and arranging the equipment such that transfer distances are as short as possible. When dough transfer equipment is required, the following points should be borne in mind:

- Whenever we work the dough we change (usually detrimentally) the dough structure.
- Dough transfer equipment usually has to handle several varieties of dough through one plant. The potential for cross-contamination should therefore be minimized by making the equipment as resistant as possible to 'dough pickup'. There are also obvious hygiene considerations.
- When handling doughs which are particularly difficult, care should be taken to avoid modifying the dough to suit the handling system. Usually the most difficult doughs are those which are wet and sticky, and the temptation is to use excessive dusting flour, oiling of the conveyors and hoppers, or to skin the dough excessively by warm air circulation systems used to 'dry' conveyor belts.

- Many doughs are sensitive to transfer times between mixer and divider or the time between mixer and moulder.
- Hoppers should be designed so that dough flow is even across their section without the risk of dough ‘eddy’ causing some dough to age excessively in the hopper.

A common reaction to problems with dough handling properties during processing is to reduce the level of water used in dough making; often this is with the intention of reducing dough stickiness. Many of the problems associated with dough during processing are induced by the interaction of the dough with the processing equipment and often arise from the effects of shear on the dough rheology. Often it is this shear which creates dough stickiness and not the recipe water level and indeed reducing the water level will not eliminate problems of dough stickiness. A fully developed dough is more capable of withstanding the impact of dough processing.

The other common reaction to handling properties during dough processing is to lower the temperature of the dough ex-mixer, in part to limit gas production by the yeast. Changes in dough density which can arise from long processing times or process delays increase the risk of dough damage during subsequent processing. However, lowering dough temperatures ex-mixer may lead to compromises in bread quality by reducing dough development as a consequence of slowing down the chemical processes which underpin development and require a compensatory increase in recipe yeast level in order to maintain a given proof time.

Dough Make-Up Plant

As described earlier, dough is delivered to the divider with most of its structural properties and rheological character already determined by the ingredients and formulation, and the bubble structure created during mixing. In these respects, further mechanical handling after mixing can only alter the outward size and shape of dough; it cannot improve the dough's structural properties but it can ‘damage’ them. The Dutch ‘green dough’ process (Chap. 2) is an exception in that it incorporates a fermentation stage after dividing and initial rounding, which changes dough rheology in such a way as to permit advantageous modification of bread cell structure. The critical issues for the dough as it is processed revolve around the degree to which the gas bubble structure created in the mixer is modified during the collective and individual processing stages before it reaches the prover. In most no-time doughmaking the ultimate bread cell structure is largely created in the mixer and during subsequent processing the bubble structure in the dough undergoes little beneficial modification. The absolute gas volume in the dough as it reaches the divider depends on the type of mixer and the breadmaking process being used, as discussed above. Generally, gas volumes in no-time doughmaking processes are much lower than in sponge and dough and bulk fermentation processes. Such differences will affect both divider weight control and subsequent moulding operations.

Dividing

In order to generate the shape and size of product we require we must first divide the bulk dough from the mixer into individual portions and then shape them to form the basis of the final product we wish to achieve after proving and baking. Dough is generally divided volumetrically, that is to say, it is cut into portions of a given size either by filling a chamber with dough and cutting off the excess (piston dividing) or by pushing the dough through an orifice at a fixed rate and cutting billets from the end at regular intervals (extrusion dividing). In either case the accuracy of the system depends on the homogeneity of the dough. This is largely decided by the distribution of gas bubbles within the dough. Where the gas structure is comprised of bubbles of uniform size and even distribution, the density of the dough remains constant throughout its volume and dividing is more accurate (for example in CBP-type doughs). Where the bubble structure is comprised of uneven sizes and distribution then dividing is accordingly less accurate (for example in bulk-fermented and some sponge and dough systems).

Dough Damage During Dividing

Compression of the dough during dividing will reduce the effect of weight irregularity due to variations in gas volumes in the dough. Any ‘degassing’ at this stage will contribute to damage of the dough structure, and so a compromise has to be found between efficiency of dividing and the level of dough damage. This means that different dividers will need to be matched to different dough types in order to give optimum dividing accuracy with minimal compression damage in each instance. For example, typically ‘strong’ North American bread doughs can withstand high compression loads whereas more delicate French baguette doughs are more readily damaged. To minimize damage to the dough bubble structure, some dividers are available with pressure compensators which permit adjustment for different types of doughs. Some dividers incorporate servo drives and control systems to limit the pressures exerted upon the dough throughout the process of dividing.

Suction damage can be much more serious than compression damage, especially if the rate of suction is not compatible with the rheology of the dough or the size and shape of the hopper and chamber. Once again, some doughs are more sensitive than others to damage. The effects of over-suction on final volume can be considerable, with evidence of individual larger bubbles in the dough structure bursting during dividing with subsequent loss of structure in products like baguette and ciabatta.

Mechanical damage occurs if dough is subject to aggressive tearing between machine parts during dividing. It can also occur when dough is pumped or transferred to the divider by a screw drive. This should not be compared with mechanical development, the difference being that the mechanical work done during mixing is uniformly distributed throughout the dough structure, whereas mechanical work during such dough transfer systems is not uniformly distributed and confers different changes in dough properties in different areas of the dough mass, which may be manifested as changes in the final product.

Two-Stage Oil Suction Divider

The two-stage oil suction divider is probably the most common bread dough divider in use. Its principles of operation are shown in Fig. 4.8. These dividers commonly have a central drive whereby the three different motions of ram, knife and slide are controlled. An essential feature of the divider is an airtight oil seal formed around the main ram and knife. Should this seal leak air back into the primary chamber, then divider weight accuracy is prejudiced and it is wear in this area that most influences long-term operational accuracy. Materials chosen for this important part of the mechanism are generally hard-wearing nickel–iron alloys designed to withstand the wear loads inherent in the system. The main knives are sometimes made from a similar, or slightly softer, alloy to encourage wear in the knife rather than the more expensive ram and main body casting. Some systems use main rams made from hard modern plastics which have self-lubricating properties and so reduce oil consumption in the system. In this case the ram becomes the main wear part. Die materials vary with manufacturer; some using the more dimensionally stable plastics and others opting for food-grade bronze alloys.

In suction dividers the dough is pushed into the division box dies under some force, and so upon ejection the release of pressure allows an increase in dough volume. This has no effect on individual weight accuracy at this point, but can cause individual dough pieces to ‘balloon’ into each other during transfer between division box and belt. These groups of dough pieces should be parted as soon as possible to avoid cross-flow of dough between pieces (this is particularly important with soft or low viscosity doughs). This separation is usually achieved by using a second conveyor running faster than the first to ‘snatch’ the dough pieces apart. It is important to note that, for the efficient running of down-line equipment, the speed of these conveyors should be linked to the output speed of the divider to provide a continuous flow of evenly separated dough pieces both across and between the batch quantities delivered by the divider.

Typical cycle speeds range up to 1800 cycles/h (although purpose-designed single-die dividers for some French doughs have been rated up to 3000 cycles/h). Where higher outputs are required multiple dies or pockets (Figs. 4.9 and 4.10) are used to achieve outputs of up to 9000 pieces/h at 1000 g (2.2 lb) with five pockets and up to 14,400 pieces/h at 120 g (4 oz) with eight pockets.

Extrusion Dividers

This type of divider relies upon the ability to pump dough, usually by means of a helical screw, through an orifice at a constant rate and density. As dough emerges from the orifice it is cut by a blade or wire at a constant rate to achieve billets of

Fig. 4.8 Two-stage oil suction divider (courtesy Baker Perkins bv)

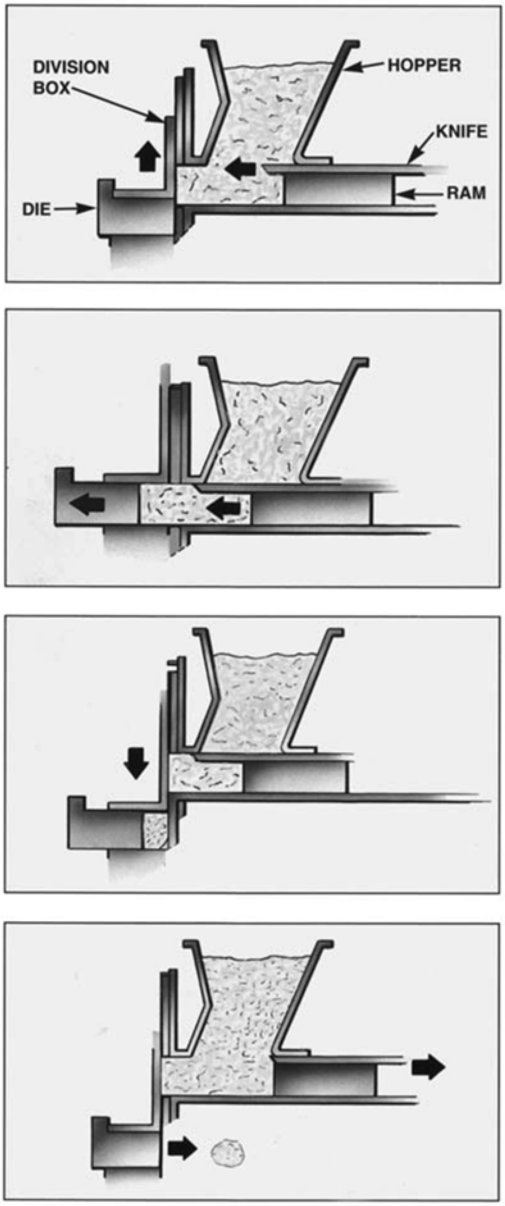

Fig. 4.9 Multi-pocket bread dough divider (courtesy Benier bv)

dough of uniform shape and size. The dough is worked considerably during this process and such dividers are best suited to strong doughs which are already highly developed. Typically such dividers are used with doughs formed using a North American bread process, such as sponge and dough. Manufacturers of these divider systems are able to claim high levels of accuracy at high outputs.

Single-Stage Vacuum Dividers

Single-stage dividers extract the dough directly from the hopper into the measuring chamber where the dough volume is set and cut via the action of a rotary chamber or mobile hopper base. The measuring piston ejects the dough piece directly onto a discharge conveyor. As there is no intermediate chamber to pre-pressure the dough, the dough hopper should be maintained at a near constant volume or the dough used should exhibit good fluidity to aid flow into the division chamber. Some manufacturers have assisted dough flow by the use of a semi-porous base to the division chamber to draw excess air from the chamber and provide some compression by suction. Single-stage dividers are commonly used where the final bread product requires a dough which has a low viscosity.

Fig. 4.10 Accurist divider (courtesy Baker Perkins)

Rounding and Pre-moulding

After dividing, the individual dough pieces are almost universally worked in some way before first or intermediate proof. If we look at traditional hand moulding methods we will see the baker kneading the dough with a rotary motion on the make-up table to produce a ball-shaped piece with smooth skin, except one spot on the base (Fig. 4.11), when two pieces are moulded (one in each hand) there is the opportunity to use the circular motion of one piece against the other and this often aids the formation of the round or ball shape. The moulding action has forced dough to move from within the body of the piece across the surface of the dough towards the base spot. This is essentially achieved by stretching the surface of the dough piece. The degree to which this can be done without permanent structural damage is a function of the rheology of the initial dough which in turn depends on the ingredients and formulation, and the characteristics of the mixing processes and divider. Further, one should note that for many hand-moulded products this process would be the one and only time the product is worked after dividing, and so it replaces both rounding and final moulding in more automated bread production systems.

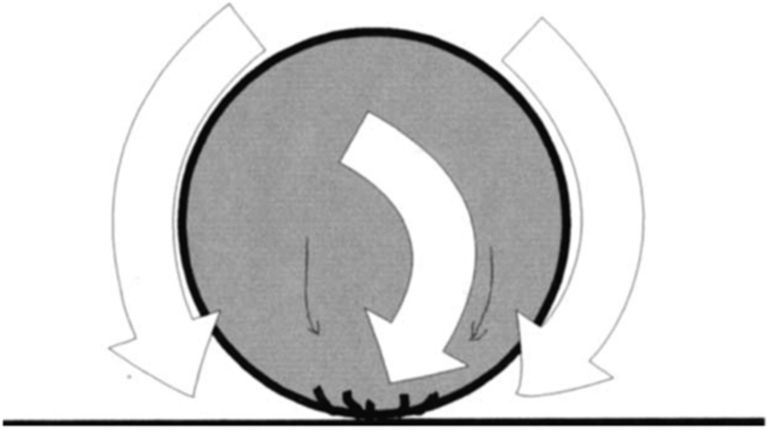

Fig. 4.11 Movement of dough around the ball during hand rounding

The action of rounding or pre-moulding adds stresses and strains which may lead to damage to the existing dough structure. However, it is clear that some breadmaking processes benefit from limited structural modification at this stage, particularly if followed by a relatively long first proof (e.g. 15 min or more) before final moulding takes place. This is seen in some forms of French baguette manufacture and is still the preferred method with many traditional British, Dutch and German bread varieties.

Some breadmaking processes require the rounder to have a degassing effect; however, if the dough has been accurately machine divided, or comes from a breadmaking process which leaves little gas in the dough then this requirement is unnecessary. In doughmaking processes where the first proof time is short, the rounder adds little or nothing to the structural properties of the final product and for a given first proof time limits the extensibility of the dough piece during final moulding and increases dough elasticity. It does, however, generate a uniform, largely spherical dough piece which makes it suitable for handling in pocket-type provers, rolling down chutes and conveying without concern for orientation. It also plays an important role in delivering a uniform dough piece to the final moulder. In some processes this may be the sole function of the rounder, but in others the dough piece may be moulded into a cylindrical shape prior to first proof. Ideally, the orientation of this shape is retained throughout the initial first proof, so that it is always presented to the final moulding system with the same side 'leading' though this is affected by the degree of tumbling experienced by the dough piece in the first prover.

The action of rounding machines is similar to that of hand rounding described above. Basically the dough piece is rotated on its axis between the two inner surfaces of a 'V', where one side is driven and the other fixed or moving at a lower speed. The dough piece quickly forms the shape of the V (hence many rounders have profiled rounding tracks to encourage a more spherical shape) and moves under the force of the driven side. The difference in speed between the two surfaces is the same but the angular diameter of the dough piece reduces as the two surfaces converge, so that the top of the dough piece is rotated faster than the bottom, effectively attempting to twist it about its axis. However, because the dough piece slips on one of the surfaces (at least one low friction surface is required for most dough types), the action is changed to one of spiralling or rolling. This is deliberately enhanced on moulding systems where the fixed surface pushes the dough piece up or across the driven one. The reader will note that the V-angle, the differential speed, the length of moulding track and the shape of the track all contribute to the moulding effect and the final shape of the dough piece.

Types of Rounder and First Shaping

There is a wide variety of rounders available where rotational speed, angle of cone, angle and shape of track, inclination of track and different surface finishes all modify rounder action on the dough.

Conical Rounders

The most common type of rounder is the so-called 'standard' (Fig. 4.12) or 'inverted' forms. They consist of a cone which is rotated about a vertical axis, with the track of the fixed moulding surface located in a spiral pattern about the outside of it. An interesting aspect of this design is that the differential speeds are lower at the top, where the axial diameter of the cone is less, hence the rounding effect changes as the dough ball travels up the cone and the forward velocity of the dough piece is reduced, causing the initial gap between dough pieces to become smaller. In inverted forms the cone is inverted and hollow with the rounding track on the inside. Versions can be found where the cone is fixed and the track rotates within it, although these are less common. With both these types the dough pieces are charged centrally into the bottom of the rounder and driven up the inner wall of the cone. Here the effects described above are reversed.

Cylindrical Rounders

A variation on the conical rounder uses a track around a cylindrical drum (Fig. 4.13). The track profile and angle of inclination are important for the final dough shape and consistency of drive on this type of moulder.

Rounding Belts

These can be classified as 'V'-type, vertical and horizontal types. V-types are simply two belts orientated in a V, at least one of which is driven. This system provides the simplest moulding concept with a conical-shaped dough piece coming from it

Fig. 4.12 Typical conical rounder, note this model has operator adjustable tracks (courtesy Benier bv)

because of the lack of a cross-drive across the moulding surface. Vertical belt rounders work in a similar manner to cylindrical moulders, with a track wrapped around a conveyor belt with the end-roller axis in a vertical orientation. With horizontal belt rounders a track is placed upon or across a conveyor with its axis in the horizontal plane. The track must be shaped to 'trap' the dough piece and cause it to be driven across the belt at an angle to that of the conveyor direction. Such rounders are generally found to be ideal for low-viscosity doughs and can be used with lower speeds and less sharp track angles for light forming applications.

Reciprocating Rounders

Here neither of the two faces of the rounder may be driven but at least one will reciprocate to present a 'tucking' action to the dough piece and give an action similar to that found with hand moulding. The reciprocating action also pushes the dough piece along the one face and imparts a forward motion to the piece. Such rounders can be either linear or 'drum-like' in operation.

Fig. 4.13 Typical vertical drum rounder (courtesy Benier bv)

Non-spherical Pre-moulding

This is basically the pre-moulding of a cylindrical shape in which shaping is carried out between horizontal belts or a belt and a board. Given that the dough piece from a divider can often be quite cuboid in shape such pre-moulding can be performed with minimal working of the dough.

Intermediate or First Proving

In most modern dough make-up processes the intermediate or first proof stage is used as a period of rest between the work carried out by dividing and pre-moulding, and final sheeting and moulding. The length of time chosen for intermediate proof period should be related to the dough rheology after pre-moulding compared with the dough rheology required at final moulding. During first proof the yeast activity begins to generate carbon dioxide gas. The extent of the activity depends on the length of time involved and (mostly) the dough temperature. There is a small effect from the temperature of the intermediate prover but more important is the requirement to prevent skinning. Because of the yeast activity the gas bubbles in the dough begin to increase in size and first proof time can be used to influence the final bread cell structure. The longer the first proof time, the more open the bread cell structure will be, provided that no degassing occurs in final moulding. A long first proof time is therefore critical in the development of products with an open cell structure, such as French baguette, and even high-speed mixing dough processes (e.g. the CBP) can be used to produce suitable baguette cell structures by lengthening the first proof (Collins 1993).

The changes which occur in dough properties as it rests are influenced by many factors other than time, and the reader must not assume that the first proof time may be simply extended until the dough has reached a 'suitable' condition for the next-stage moulding process. This is particularly the case where reducing agents (Chap. 3) or proteolytic enzymes are used to improve dough extensibility, since extending the first proof time may eventually adversely affect dough rheology and final bread quality rather than improve it. In some breadmaking processes the changes in dough rheology which may occur in first proof can have a considerable effect on final bread quality. This is the case in no-time doughmaking processes, such as the CBP, where the elimination of first proof can lead to a reduction of loaf volume and an increase in damage to the bubble structure in the dough when ascorbic acid is the only oxidant in the recipe. Enzymic action may also be enhanced during first proof, the total effect depending on the time and temperature conditions used.

In some dough processes the first proof period is used to enhance the fermentation process, in particular the traditional Dutch green dough process (Chap. 2), where the first proof time may be as long as 50–75 min (sometimes with a second rounding midway through proving). Here it is claimed that the resting time, as well as temperature and humidity within the prover, allow 'natural' dough conditioning to take place, thus requiring lower levels of reducing agents and other dough improvers to be used.

Where first proving times are long and the water content of the dough is high, care should be taken to ensure that the prover air is conditioned to prevent skinning (in cool, low-humidity environments the temperature and humidity should be increased) or sticking (in warm, high-humidity environments the temperature and humidity should be reduced). Care should also be taken when trying to enhance the 'resting' process by raising the humidity and temperature in the cabinet of a pocket prover, since condensation occurring on the dough pieces will encourage sticking of the pieces to prover pockets with subsequent transfer problems. Ideally, the first proof time is a function of recipe and bread type and as such should remain constant. However, within limits first proof times can often vary with actual plant speed in order to ensure that some plant in-feed systems and subsequent moulding machines receive a balanced supply of dough pieces regardless of plant speed.

Pocket-Type Prover

Where first proof times of longer than 1–2 min are required the most common method of achieving this is by means of pocket-type provers where dough balls are transferred into ‘pockets’ or ‘troughs’ for the whole of the resting period (Fig. 4.14). The pockets are held in ‘frames’ which are in turn fixed between two chains carrying the ‘swings’ around the proving cabinet from charging to discharging stations. Either due to condensation or capillary action between the dough piece and the pocket surface, the dough piece can stick to the pocket if left in contact with it for too long. Hence, pocket-type first provers with times longer than 5 min often incorporate turnover devices which roll the dough piece from one pocket to another allowing the temporarily empty pocket to dry in some cases and allowing the simple rolling action of the dough ball to alleviate the problem in others. Where the charging method does not fill all of the pockets in a swing, these turnover devices are also used to transfer dough balls across the swings to the discharge side of the prover.

Fig. 4.14 Pocket type first prover (courtesy Benier)

First Prover Charging Methods

Dough balls from rounders and pre-moulding devices on bread production lines are transferred in a single stream of pieces into the pocket prover, such that at fully rated capacity every pocket of the prover is filled. Because of the slippage in the rounder, the pitch of dough pieces coming from it is not always constant and they must be synchronized to fall properly into the prover pocket. This task becomes more critical at higher throughputs, and so a variety of loading methods are adopted to cater for different dough types, sizes and throughputs.

Single-piece in-feed with intermittent prover drives (sometimes referred to as ‘park and ride’) receives one dough ball at a time at one charging point. As each dough ball is charged into a pocket, the swing chain is driven until the next swing is at the charging point and waits for the next dough ball. Note that the actual first proof time achieved is a function of the dough ball supply rate and not preset by the prover drive system. Also, the prover will only discharge whilst dough pieces are arriving, so a discharge switch is required for the end of a production run. This method is very common with throughputs below 1200 pieces/h.

Indexing Conveyors

These are used when feeding a continuously running prover at up to 2000 pieces/h (more commonly 1500 pieces/h) for single-pocket filling or 3000 pieces/h for twin-pocket filling. Basically the conveyor stops and starts to synchronize the dough ball to the prover operation. Twin-pocket systems feed a valve or ‘gate’ which diverts the dough piece to side-by-side pockets, while in some systems the conveyor itself swings from one position to another. Note that two pieces fed at a time means two pieces discharged at a time.

Pusher In-Feed Systems

For throughputs of up to 7000–8000 pieces/h this is the most common form of prover loading system and the type usually found in industrial bakeries with pocket-type first provers. Simply the dough balls are placed on a conveyor travelling across the front of a pocket prover. The pitch between the pieces must be the same as the pocket pitch. When a batch of dough balls are aligned before a swing, a pusher bar rolls them all into the pockets of the swing. Different manufacturers have variations about this theme with different swing widths (six, eight, ten or 12 pockets per swing) and differences in pusher bar design and action. The most critical aspect is the timing of dough balls onto the transfer belt. Some systems use re-pitching conveyors to correct errors occurring in the rounder and transfer conveyors, while others gear the divider and rounder speed to the prover speed to maintain constant dough ball pitching.

Pallet In-Feed Systems

Pallet loading systems are used at higher speeds but have some limitations with respect to dough type and size at higher outputs. They are commonly used with firm doughs and smaller dough weights at throughputs greater than 7000 pieces/h. The principle of operation is that of a series of shallow troughs ('pallets') travelling across the front of the prover as the conveyor for the pusher in-feed system. Each of these pallets is filled with a dough ball, and when the pallets are aligned above individual chutes, each feeding a prover pocket, they swing open, dropping the dough balls down chutes into the pockets of the waiting swing. The actions of both pallet conveyor and swings have to be synchronized, and again a critical aspect of the system is the placement of dough balls into the pallet.

Discharging

Where more than one dough piece leaves the first prover at the same time they are often synchronized with valves to the subsequent discharge conveyor. On higher capacity lines, two swings are sometimes discharged simultaneously to feed separate final moulders.

Conveyorized First Provers

In order to eliminate the need for complex pocket prover in-feed systems, some industrial bread producers modify their recipe and process in order to eliminate or considerably reduce the need for first proof times greater than 1–2 min. This then makes simple conveyor transfer of dough pieces from rounder to moulder a practical consideration. If a slightly longer rest time of up to 3 min is required then spiral conveying systems can be used to provide the residence time required. Some producers eliminate the rounder, so that a simply moulded cylinder of dough is conveyed (appropriately orientated) directly to the final moulder.

Final Moulding

Throughout this chapter the reader will have noted how dough make-up machinery has been developed to copy or simulate the original manual process and later superseded by subsequent alternative processes. Modern moulding machines still sheet, curl (or roll) and mould the dough in simulation of the traditional manual process, with four-piecing and turning of the dough pieces prior to panning for some bread types.

When moulding dough for single-piece sandwich pan bread the objective is to achieve a cylindrical dough piece with roughly squared ends and a dough piece with a length and diameter equal to those of the bottom of the pan. For single-piece ‘farmhouse’ bread the objective is to achieve a cylindrical dough piece with hemispherical ends where the length and diameter of the dough piece are equal to those of the farmhouse pan. In the production of four-piece sandwich pan bread the objective of moulding is to achieve a cylindrical dough piece before four-piecing with flat ends where the length is four times the pan width and the diameter is one-quarter of the pan length. For baguette and bloomer the moulding requirements are such that the dimensions of the moulded dough pieces are close to the size ultimately required when fully proved. Other bread types may require hand finishing to achieve their traditional shapes, with the exception of large cobs or coburgs (round shapes) which may be finished in rounders properly designed for that purpose. All of the dough shapes described above (with the exception of cobs and coburgs) undergo extensive sheeting and curling prior to passing under the final moulding board.

The reader will note from previous sections that the majority of dough make-up processes utilize a rounder for initial handing-up of the dough piece prior to the first proof so that it is usually presented to the moulder as a sphere or more correctly a slightly flattened sphere. By studying Fig. 4.15 we can see that when such dough pieces are sheeted they become elliptical in shape which on curling gives an ellipsoid-shaped dough piece. Final moulding of this piece requires additional work to generate the ultimate cylindrical shape with the following effects.

- Because the dough piece is ellipsoidal, the drive between the moulding belt and board is only effective in the centre of the dough piece, where a greater frictional force is exerted. This causes a twisting action between the centre and ends of the dough piece. The reader may test this by drawing a line along the outside of an

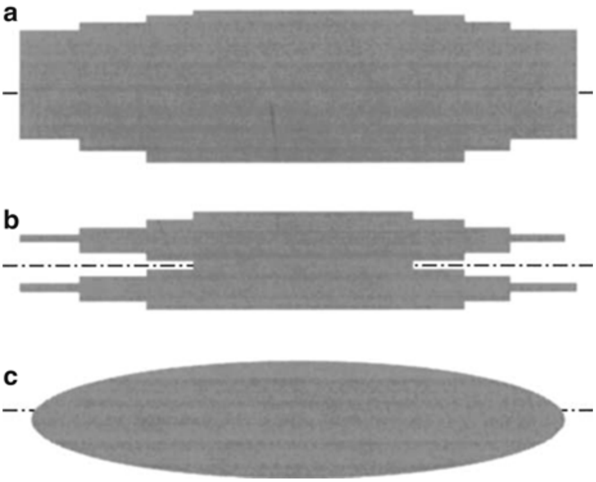

Fig. 4.15 (**a**, **b**) show the theoretical lamination structure of dough in a sheeted and curled piece ((**b**) being a cross-section of (**a**)), and (**c**) showing the final ellipsoid shape achieved

ellipsoid dough piece and passing it under a flat moulding board. The resultant moulded piece will demonstrate the conversion of this line into two opposite-handed spirals emanating from the centre of the dough piece.

- Because the dough piece reaches its required length before its desired shape the ends begin to press into the side guides of the moulder, which causes additional drag and twisting as the centre pulls the ends of the dough piece along the side guides. When this is done, the internal structure at the centre collapses and dough quickly migrates to the outer edges, forming an 'hour-glass'-type shape. On conventional baguette moulders with no side guides the external surface at the centre is damaged by over-moulding, causing immediate shrinkage of the centre of the dough piece as it exits the final moulder, and a bulge appears in the centre of the piece.
- Since the initial ellipsoid has concave ends, in some systems large air bubbles can be entrained into each end of the final dough piece.

If we now compare the above with a moulding system presented in which a dough piece is already cylindrical in shape (Fig. 4.16), we will see a sheeted dough piece of roughly rectangular shape, curled to a cylindrical shape and (particularly if already the correct length) moulded lightly to eliminate the moulding seam and finished at the ends.

Given the above, we can observe that in order to achieve the quality of product seen from bread producers today the dough must be fully relaxed (i.e. have a low resistance to deformation) and suitably plastic when entering the final moulding stage. This is particularly true when starting from a rounded dough ball. As discussed above the removal (or significant shortening) of the first proving stage is greatly assisted by the removal of the rounder and the proper presentation of the dough piece to the final moulder, though there can be other adverse effects. It is essential that the dough piece is presented centrally to the rollers and is maintained centrally throughout the moulding process (Cauvain and Collins 1995). A typical mechanism for achieving such centralization is shown in Fig. 4.17.

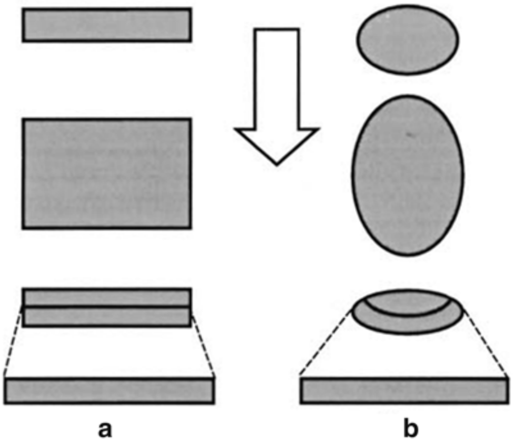

Fig. 4.16 Sheeting, curling and moulding from (**a**) a dough cylinder and (**b**) a dough ball

Fig. 4.17 Dough piece being centred before sheeting

Sheeting Action

Sheeting requires the dough piece to be positioned between pairs of rollers in order to reduce its thickness, either a single set of rollers or consecutive pairs of rollers. During this process the thickness of the dough piece can be reduced by up to one-tenth and the surface area increased by a factor of more than three. We should note that this represents a considerable reworking of the dough structure. The prime objective is to stretch the cell structure and to close the relaxed open cells delivered by the first prover. The sheeting action cannot degas the dough piece unless the latter has some particularly large gas bubbles (as distinct from bubbles which will become large cells) caused by lengthy first proving, poor distribution of ingredients during mixing or inadequate degassing of fermented doughs during dividing and rounding. Similarly there is little evidence that any gas cells are created during sheeting. However, given the extent of the reworking some inter-cell walls must be broken whilst others must be stretched and thinned to a considerable extent.

The design of sheeting rollers differs between manufacturers. Some systems favour consecutive sheeting rollers of fixed but progressively narrowing gaps, while others favour larger drum and roller sheeting systems where the dough piece is reduced once between a non-stick roller and a drum (Fig. 4.18). Some manufacturers of the latter provide adjustable sheeting pressure using springs or compressed air, claiming that they make the sheeting action more responsive to the rheology of the dough passing through the gap. Certainly the gap reduction and roller speed ratio reflect the rheology of the dough. If the gap is narrow and the roller speed too

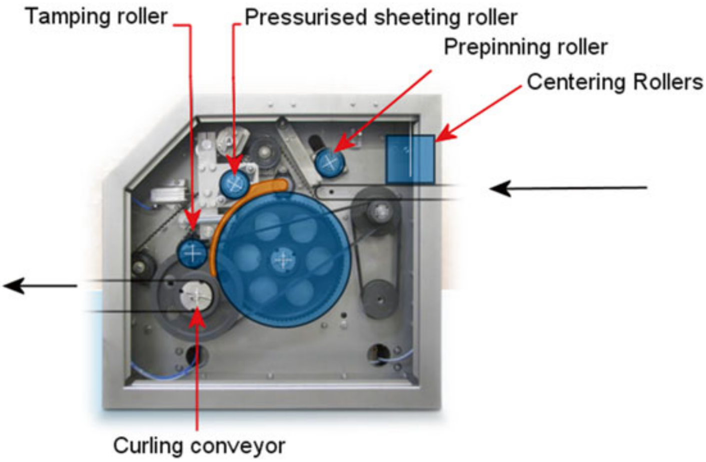

Fig. 4.18 Drum and roller sheeting action (courtesy Benier bv)

high for the dough rheology, then 'scrubbing' will take place either between the roller and the dough piece, or between the inner and outer structures within the dough piece. When this occurs there is excessive damage which will show as tear marks on the dough surface. Relative roller speeds may also be critical where multiple sheeting sets are combined. Subsequent sheeting sets can be set to run at speed such that the dough sheet may undergo some "stretching" as well as "squeezing". Some manufacturers supply multiple roller sheeting systems with independent drives capable of being "tuned" to the rheology of the dough being processed.

Curling

Having achieved a sheet of dough it is then commonly 'curled' to form a 'Swiss roll' effect as illustrated in Fig. 4.19. Unlike a true Swiss roll, there should be no intermediate layers and in particular no air should be trapped between adjacent dough surfaces. Many systems achieve adequate curling by hanging a mesh belt along the moulding belt (Fig. 4.20) before the moulding board so that curling is achieved by the mesh dragging on the leading edge of the dough sheet and causing it to roll back over the following portion of the sheet. Some systems start curling in this manner and finish it under the moulding board. Other systems curl long sheets at high throughputs and incorporate a driven mesh belt (Fig. 4.21) acting against the direction of the moulding belt and so shorten the length of the moulder in this area. Whatever the curling method employed it is essential to minimize trapped air pockets during curling as these will directly contribute to the formation of unwanted holes in the baked loaf.

Fig. 4.19 Dough piece after curling

Fig. 4.20 Hanging curling chain

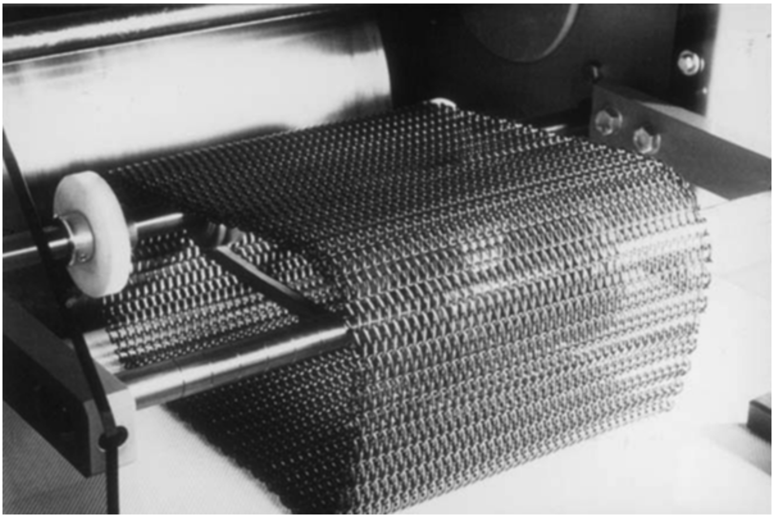

Fig. 4.21 A driven curling chain

The Final Moulding Board

As discussed above, considerable reworking of the dough can occur during final moulding for only a small dimensional change. It is important that the dough retains a degree of extensibility as it leaves the curling section prior to final moulding. Damage is minimized if the moulding pressure is minimized to encourage 'dough flow' rather than forcing it. It is therefore considered that a long moulding board with gradually reducing moulding gap is more 'dough friendly' than a short board with a narrow gap. Side guides should not be set in order to reduce the dough piece. This will cause extensive rubbing of the dough piece on the side guide incurring surface damage. In extreme cases the drag offered by the side guide will cause the dough piece to assume an "ox bow" shape. Under these conditions the dough centre undergoes a wringing action which can cause a break down in dough structure at the centre of the dough piece and may adversely affect final product shape with free-standing breads (Cauvain and Young 2009). The materials of the belt, board and side guides are chosen to allow some slippage as the dough piece is extended, and will reduce surface damage particularly when moulding doughs for baguettes, sticks or batons.

Four-Piecing

The objectives of four piecing are to cut the dough cylinder into four equal lengths (each equal to just less than the tin width), sometimes each piece is joined by a tail of dough to one or more others and turned through 90° to lie side by side across

Fig. 4.22 Typical bread dough moulder for four-piece bread (courtesy Benier bv)

the tin when panned (Cauvain and Young 2001). In other cases the pieces are completely separated from one another. To maintain control, the dough pieces are cut under or immediately after leaving the moulding board. Dough drag on the side guides should be minimized or accounted for when setting the gap between cutting blades. Further, the depth and length of the blades should be appropriate if dough tails are required during turning and panning. Side guides should finish before the end of the moulding board if not during mid-cut, especially if side guide drag is present. Typical bread moulders for four-piece bread are shown in Figs. 4.22 and 4.23. After the moulding board the pieces are 'knocked' into a 'W' (when viewed from the discharge end) as they fall over the end of the moulding belt onto a panning conveyor. The pieces are then pushed parallel between converging belts, rollers or plates and panned into the tin. It is important for subsequent processing that the panned dough pieces lie flat and parallel to one another in the tin in order to deliver the required effect on crumb cell structure, see below.

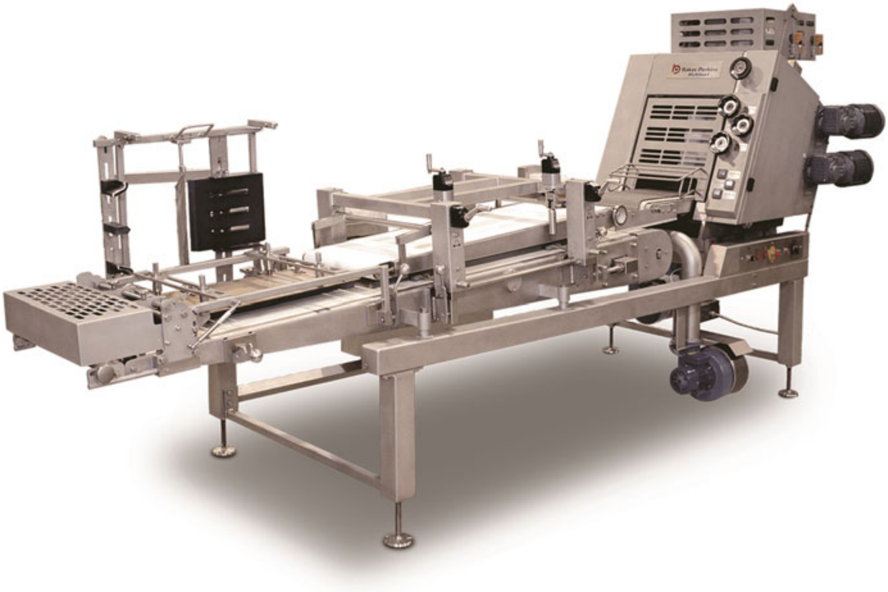

Fig. 4.23 Multiplex final moulder (courtesy Baker Perkins)

Cross-Grain Moulding

One method of achieving a wide sheeted dough piece prior to curling and moulding is to turn the sheet through a right angle so that the wider plane of the elliptical sheet is presented to the curling chain and moulding board. Besides the obvious advantage of reducing the work required during moulding, this method presents the elongated cells achieved during sheeting across the dough piece rather than around it, hence the term ‘cross-grain’. Although in practice there are fewer dough layers after curling, equipment manufacturers claim that this presents a cell structure in the finished single-piece loaf which is similar to that found in four-pieced bread.

Other Sheeting and Moulding Systems

Where shapes of particularly long or narrow cross-section are required, special equipment is available to enhance the principles of dough moulding previously discussed. Many examples of these are used on automated baguette plants, where different designs of contoured moulding boards are used to encourage dough piece elongation. Similarly, some manufacturers use diverging ‘polycord’ conveyors above and below the dough piece to pull it out to a greater length. One manufacturer has patented a reciprocating upper moulding belt which reduces the twisting effect seen during final moulding.

Modification of Gas Bubble Structures During Processing

In the dough processing steps which follow mixing and precede the entry of the dough pieces to the final prover there are significant changes in the rheological properties of the dough pieces and the gas bubble structures contained within them. In modern no-time doughs the gas bubble structure created in the mixer is essentially the one which will be expanded in the prover and set in the oven. There will be some expansion of gas bubbles during dough processing but it will be relatively small by comparison with that which will be achieved in the prover and the oven. The interactions between dough rheology and moulding operations have to be optimized if damage to gas bubble structures in the dough is to be avoided. The most common manifestations of damage to the dough bubble structure are the formation of large holes and streaks of dull or dark coloured crumb (Cauvain and Young 2001).

Modern no-time doughs have considerably less gas within them when they reach the divider by comparison with those prepared by bulk fermentation. The upper limit of gas volume with no-time doughs is in the region of 20 % depending on how the dough has been prepared while in the case of bulk fermented doughs then a figure of 70 % would be more appropriate. By the time that both doughs reach the final moulder the figures for no-time doughs are 17–18% and for bulk fermented doughs around 25 % (see Table 4.2). It is clear from these data that considerable degassing of the bulk fermented doughs occurs but the no-time doughs remain essentially unchanged.

The formation of voids or holes in the bread is commonly associated with dough processing, especially moulding. Often the holes are attributed to pockets of gas trapped within the dough at various stages. There are a number of opportunities for the occlusion of large gas pockets during dough processing but they are mainly associated with curling and the change of dough shape in the final moulder. Cauvain (1996, 2002) used Computerized Tomography (CT) to show that while voids may be occluded in dough pieces leaving the divider they did not survive the sheeting rolls, or if they did they had to be smaller in size than the gap of the last pair of rolls. This showed that the origins of many of the larger holes were most likely to come during the curling process since they were mostly situated towards the ends of the dough piece.

Table 4.2 Effects of sheeting on gas volume in dough

	Proportion of gas by volume (%)		
Dough processing stage	Fermented	CBP	Spiral
End mixing	5	5	7
End fermentation	70	–	–
End first proof	27	16	18
End moulding	18	15	17

Other holes which may form in the dough are likely to do so later during proof and the early stages of baking. Such holes are most likely to arise because the delicate bubble structure in the dough has been damaged, often because of the application of high pressures when the dough piece passes underneath the final moulding board. The high pressures are often used to 'mould out' trapped pockets of gas but in many cases create the very problem concerned. The mechanical breakdown of the gluten network between gas bubbles allows them to expand more readily and coalesce when they touch. The increase in bubble size which occurs creates localities of relatively lower pressure and the carbon dioxide gas from yeast fermentation preferentially diffuses into them. Thus the larger gas bubbles expand while the smaller ones remain relatively unexpanded. If the expansion is sufficient then a hole may remain in the final product. The rheological properties of the dough during final moulding are very important in reducing dough damage and unwanted hole formation with 'stiff' doughs being more susceptible to damage (Cauvain and Young 2008).

Cauvain and Young (2006b) illustrated how the structure of bread which had been processed by four piecing varied in a systematic manner along the length of the baked loaf (i.e. from piece to piece). They suggested that the areas within each of the four pieces was dominated by a rounded cells structure while the areas where the pieces met in such bread (3 in all) were dominated by elongated cells. The uniformity of such structures is a direct consequence of the efficiency of the moulding, cutting and panning operations associated with four-piecing.

Sheet and Cut Dough Processing Systems

It has long been recognized that the gluten network and the gas bubble populations in dough should be subjected to as little mechanical pressure as possible. This is especially true of doughs required for the manufacture of French and Italian breads (baguette and ciabatta) which also require high water additions to create the characteristic open and random cell structure. In recent years the concept of 'stress-free' dough processing equipment has developed in order to handle high water doughs and manufacture open cell structure products. In one sense the term 'stress-free' is misleading since any handling of the dough to change its shape subjects it to stress. A more appropriate term would be 'reduced-stress' (Cauvain 2001). In reduced-stress dough processing systems the bulk dough is fed as a sheet onto a conveyor. The width of the dough sheet is adjusted to be constant before it is split into narrow strips. A guillotine knife arrangement divides the narrow strip into a series of units of the required weight and individual dough pieces move on for moulding into the appropriate shape. The avoidance of sheeting rolls ensures that the dough is not significantly de-gassed and the bubble structure within is largely preserved. Such sheet and cut systems are suited to the manufacture of artisan-type products which do not require the regularity of shape associated with products such as sandwich breads though they can be used to manufacture the latter.

More recently there has been interest in adapting lamination employed in the manufacture of puff pastry but without the incorporation of a fat layer. Essentially it is the process of folding the dough sheet which is being exploited in order to manage the stresses concerned with shaping.

Panning and Traying Methods

As bakery plant speeds and moulder speeds have increased so panning processes have to cope with faster throughput capacities. Most manufactures offer simple drop systems whereby the tin or tray is indexed under the discharge point of the final moulder as each dough piece exits the machine. Faster systems use retraction belts in order to fill a complete stationary strap or tray of sufficient dimension to allow it to be indexed between fillings. Other systems will synchronise the flow of tin strap/tray and dough product such that dough pieces are panned "on the move". In plants where the dough piece has been cut in order to make several products from one dough piece (e.g. baguettes strings cut form to petit pains) the panning unit may be combined with a separating unit in order to space products on the receiving tray or fillet.

Equipment for Small Bread and Rolls

Previous sections have referred to dough handling equipment after the mixing process as separate dividing, rounding, proving and moulding machines. In the production of small breads and rolls it is common for these functions to be brought together in one piece of equipment or plant. A roll plant, however, still contains within it the various stages of dough make-up used for bread processing and the same dough-handling constraints will be relevant.

Small bun Divider Moulders

The divider principle used here is the same as that found with hydraulic dividers previously mentioned. Manual versions are available where pressure (to distribute the dough evenly under the knives) is applied by a lever. The dough is cut by the downward movement of the knives from the head mechanism. After dividing the cut dough pieces moves in a rotary motion to round the pieces between the plate, the knife walls and the top platen. Dough may be manually loaded into the machine on the plate, which is later removed with the rounded dough balls on it. Typical small bun divider moulders will produce between 15 and 36 dough balls per cycle with

Fig. 4.24 An automatic bun divider–moulder (courtesy Daub Verhoeven)

weights from 18 to 160 g depending on the model and manufacturer. Automatic versions which pressurize, cut and mould the dough are available (Fig. 4.24). Some have adjustable timers so that the length of the moulding period can be adjusted. Typical production rates are operator dependent, but capacities of up to 5000 pieces/h are possible.

Integrated, Multi-lane Roll Plants

Such plants are the most common type of equipment used for roll production. Output capacities vary from 4000 to 36,000 pieces/h depending on the number of 'rows' of product being processed and the speed of the plant per row. Depending on the type of product to be made, processing modules are added to the basic specification in order to achieve the different moulding, cutting, seeding or stamping effects. All such lines usually incorporate a divider–moulder which can use a combination of dividing and rounding, as already discussed. Two-stage dividing is still the most common, but without the use of oil or a knife, as found in the oil suction divider. Extrusion dividing is more commonly found, particularly in the production of burger buns and hot dog rolls, where the dough consistency is usually based on highly developed North American doughs with low viscosity and good flow characteristics (Chap. 9).

Rounding is largely based on the oscillating system described previously for the bun divider–moulder and the linear rounder. This is applied differently by different manufacturers, some moulding the dough piece between an oscillating cup and a processing belt, some incorporating the oscillating motion into a honeycomb frame mounted around a drum and others combining the dividing chamber with the moulding system to mould against an oscillating plate. Extrusion dividers commonly round by means of a linear rounding track mounted over a processing belt. Spreading belts are usually incorporated into the divider–rounder to alter the pitch dimension between rows before the next processing module or unit. This allows the individual rolls to be pinned out later to longer finger or hot dog rolls whilst maintaining clearance for later expansion during proving. Swing-type first proving modules are incorporated when higher levels of dough reworking are required to develop the final product shape and always when the dividing and rounding action is aggressive or the rheology of the initial dough is particularly poor. Moulding can be achieved with a board or contra-rotating belt as described earlier. Some products may be simply rolled to shape while others may be sheeted and rolled. Dough pieces for burger buns can be pinned simply to flatten the rounded dough piece to a disc.

The seeding and topping of fermented products is more commonly found prior to the final proof on roll lines than on bread plants. Hence it is common to find seeding systems incorporated into roll plants in which the roll dough piece is first wetted and then sprinkled with seed. Excess seed is returned to a collection bin for later use. Panning is usually onto flat or indented trays. Panning methods can consist of row-by-row panning similar to that seen with bread lines where the tray indexes under the panning point are in line with the flow of product or more commonly by a retracting belt which rapidly withdraws under the dough pieces to drop up to a tray full of dough pieces every cycle.

Combination Bread and Roll Plants

Some smaller plants combine the requirements of bread and role production into one largely automatic operation. The equipment is aimed at the smaller and in-store bakeries. The dough is mixed in the spiral mixer and after mixing is completed the dough is automatically extracted from the bowl and fed directly into the divider. The divided dough pieces are rested and transported to the appropriate final moulders and afterwards panned or trayed up by the one operator needed to run the plant. The settings required for the various product types are stored in a computer. The program chosen by the operator automatically controls the various process stages and choice of equipment so that the skill and manual input required of the operator are limited.

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Chapter 5
Proving, Baking and Cooling

Introduction

Proving, baking and cooling are the stages of breadmaking that convert a fermenting dough into a stable product ready for consumption. There is evidence that leavened products were made in Egypt around 2000 BC and unleavened bread has been made since prehistoric times. The three operations, proving, baking and cooling have been essentially the same ever since first discovered, relying on the properties of the raw materials and the way they behave when heated to produce a staple product that is both nutritious and good to eat. How the process was discovered we shall never know in detail but the huge variety of leavened bread products eaten across the world today all rely on the same basic principles. Proving, or proofing, allows time under favourable conditions for the yeast and enzymes in the flour to remain active. Then, during baking, the rate of heat transfer is increased so that the outside of the loaf dries to a crust and inside, the starch swells, the protein coagulates and gasses expand. Cooling reverses the direction of heat transfer and aims to produce loaves that are ready for wrapping, often with slicing as an intermediate operation and storage. A typical timescale, with process conditions and their effect on loaf core temperature, is shown in Fig. 5.1.

Like many other processes in the food and drink industries, the details of the physical mechanisms and chemical changes occurring inside the dough during its various processing stages are extremely complex and only comparatively recently has it been possible to argue that breadmaking has become more of a science than an art. In the last 60 years, as more sophisticated measurement and microscopic techniques have been developed, our understanding of the changes that occur during baking has advanced dramatically, increasing many-fold the resources available to the baker, particularly in the case of ingredients, where flours, enzymes and special yeasts can be obtained, tailored for specific purposes (Chap. 3).

The ready availability of significant computing power means that dynamic models can now be constructed for the heat and mass transfer during baking, and

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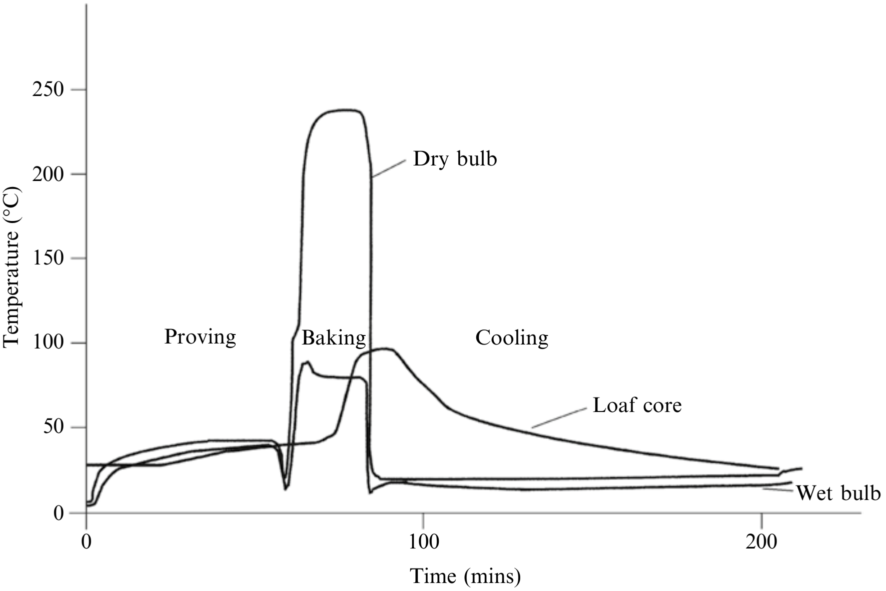


Fig. 5.1 Proving, baking and cooling

computational fluid dynamics (CFD) can be used to visualize the air flows and heat transfer both in the processing chamber and also around and within the product. A plot of air velocity vectors in an oven chamber with a blowing nozzle, strip burners and an extraction point is shown in Fig. 5.2. The application of imaging techniques has now extended to the use of X-ray tomography which has enabled the dynamic development of the internal processes which occur during proving and baking to be visualized (Whitworth and Alava 1999; Cauvain 2004)

A better understanding of these heat transfer mechanisms has not led to any major breakthrough in the design of the equipment to prove, bake and cool bread. The basic designs are well established and have developed in an evolutionary fashion, mainly to support increases in output and improvements in consistency and reliability. Every country has traditional breads, for some of which quite special baking conditions are required, but as a popular product spreads around the world, there is a tendency for its characteristics to change slightly to conform to the requirements of high-volume production on modern equipment. This tendency towards standardization makes it legitimate for this chapter to assume that the bread is being baked in tins or pans, as the processes used are substantially the same as for other specialty breads that may be proved and baked on flat plates.

Figure 5.3 illustrates a variety of popular bread products and the choice of the range of products to be made and their characteristics will determine how the plant is configured and adjusted. Some important considerations are as follows:

- What are the required crust and crumb properties?
- Is the surface to be glossy?

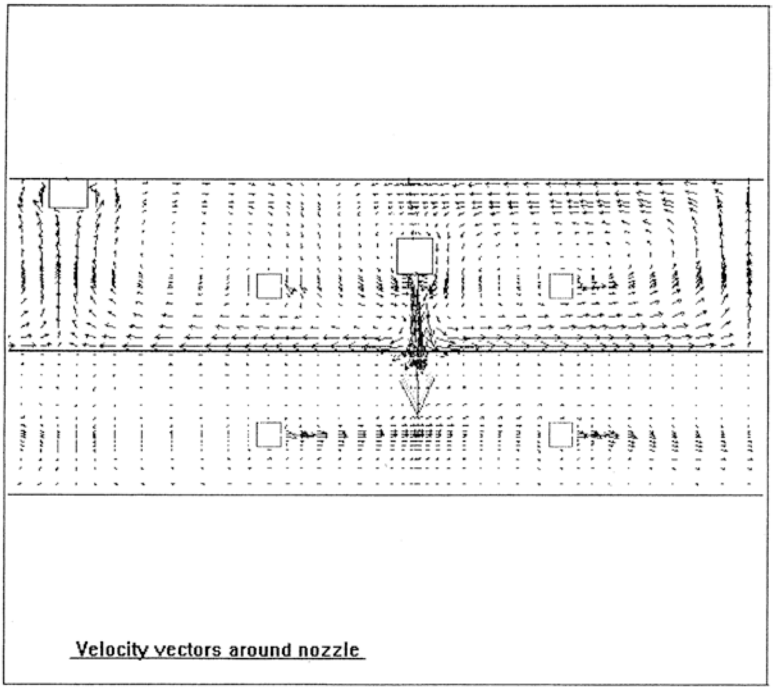


Fig. 5.2 CFD representation of a baking chamber

- Does the loaf have to be sliced?
- What must the final moisture content be to meet the yield target or legislative requirements?

All these properties can be manipulated by changing the heat transfer programmes, although they are not, of course, independent of the recipe formulation and mixing regime. This chapter does not contain any formulae, but attempts to explain qualitatively the mechanisms at work, in the belief that an understanding of what is happening during the later stages of the breadmaking process will be of more use in achieving the required product characteristics and in overcoming quality problems than will a list of specific instructions or pages of photographs of defective loaves.

The properties of air and water mixtures are fundamental to the understanding of proving, baking and cooling, so a short refresher course on psychrometry has been included after this introduction. Production bakers will also be interested in production costs and in maintaining the performance of their heat transfer equipment and some routine procedures are suggested to help them to monitor the state of the plant. Trends in equipment design are also indicated in each section and the promise of emerging technologies is discussed.

Fig. 5.3 Bread variety

Psychrometry

Definitions

Dry bulb temperature is the actual temperature of a gas. **Dew point temperature** is the temperature of an air and water vapour mixture below which condensation of vapour will begin. **Saturation** is the condition of the mixture at the dew point temperature.

Relative humidity is the ratio of the partial pressure of the water vapour in a mixture to the saturation pressure at the same temperature. It is a concept that is very useful for air conditioning work, but for process work at higher temperatures, dew point is often more useful when trying to visualize whether the dough surface will be experiencing condensation or evaporation.

Wet bulb temperature is the temperature indicated by a thermometer in an airstream when the bulb is kept wet. It is not an absolute physical property like dry bulb and dew point temperatures, but it is easier to measure and can be used to estimate the relative humidity, from tables.

Specific humidity is the mass of water per unit mass of dry air in a mixture of air and water vapour.

A psychrometric chart (see example in Fig. 5.4) is used to compute the condition of air and water vapour mixtures during heat and mass transfer processes, of which proving, baking and cooling are typical examples.

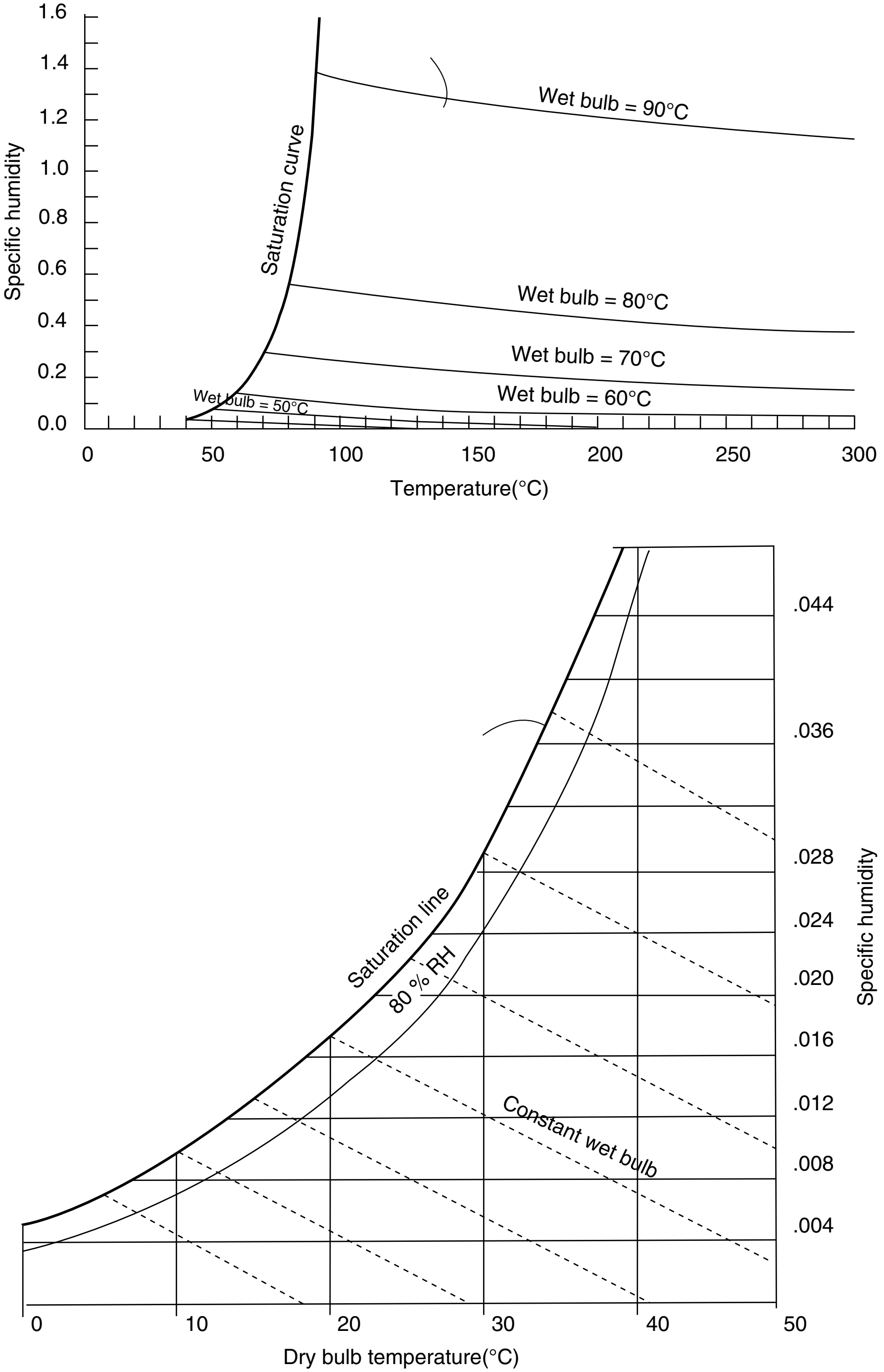


Fig. 5.4 Psychrometric chart

The Proving Process

Proving, or proofing, is the name given to the dough resting period, after the moulded pieces have been put into tins or outer trays, during which fermentation continues in a controlled atmosphere. Fermentation is a blanket description for a series of complex, interlinked reactions, which are dealt with in more detail in other chapters. To understand proving, a simpler model is sufficient. Starch is converted into sugars by enzyme action. The sugars feed the yeast and the breakdown products are carbon dioxide and alcohol. As carbon dioxide is produced it is retained in the tiny cells formed in the protein matrix during mixing, causing the cells to grow and the dough to expand. The number of cells cannot be increased during proving, but the structure can be coarsened, and if the dough is over-proved then the cell walls will start to collapse. Other products of yeast (and bacteria) activity, mainly acids, are also formed during proving and they can contribute significantly to flavour development.

If baked in a pan the dough is confined by the walls of the tin and this helps to determine the shape and orientation of the cells in the final product. For example, a dough piece that has been divided into four or six pieces and laid to fill the bottom of the tin will finish with uniform, vertically elongated cells, whereas a single piece, too short to fill the tin, can expand in length as well as height and the final loaf crumb will not look as white or bright as its multi-piece competitor. Figure 5.5 illustrates diagrammatically how the cells grow and elongate as the dough piece volume increases and the outside skin of the piece slides up the oiled or non-stick surface of

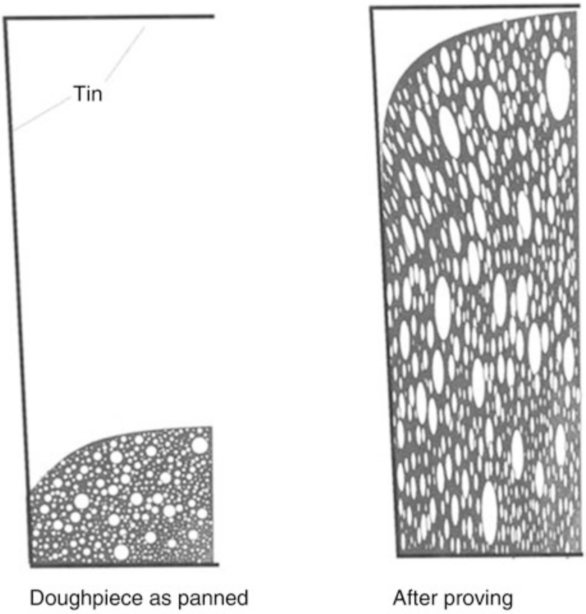


Fig. 5.5 Effect of dough piece and tin shape on cell structure

the tin. In reality the cells in the dough will not be round to start with and they will have been aligned by whatever moulding has taken place into a starting pattern, which will then be subjected to expansion.

Examination of CT images of dough pieces proving in a pan (Whitworth and Alava 1999) show that there is greater expansion in the lower half of the piece than the upper portion. In part this occurs because conducted heat readily reaches the dough piece from the walls of the pan in the early stages of proving. As the dough piece begins to fill the pan heat transfer to the centre of the dough is slow but the gas pressures generated by the rapidly proving portions of the dough push the centre of the dough upwards. By the end of proof the original centre of the dough piece is about two-thirds of the way up the pan. This portion of the dough piece is somewhat cooler than the rest of the dough and will make a major contribution to oven spring during baking. In oven-bottom (hearth) breads and those supported during proof and baking in slings (e.g. baguette), the expansion of the dough during proof is more uniform and the centre portion of the piece remains more or less central during proof.

As the gas bubbles in the dough begin to expand during proof the gluten network which surrounds them begins to stretch. As the dough continues to warm a point will be reached when gas bubbles begin to touch. If the gluten network is not able to stretch sufficiently to cope with the bubble expansion the gluten films may rupture and touching gas bubbles may coalesce to form a single larger gas bubble. The coalescence of gas bubbles may occur throughout the dough piece during the proof phase, especially if the gluten network does not have the necessary properties to accommodate bubble expansion (Campbell 2003). It is now evident from X-ray tomography (Cauvain 2004) that significant coalescence of gas bubbles does occur in doughs made with low protein (weak) flours in the prover, as well as in the oven.

Providing it can be done without compromising product quality, there is an obvious requirement to minimize proof time—a longer time represents a bigger proving chamber, which means higher capital cost and more space, more work in progress and longer product changeover times. This means optimizing the conditions for fermentation so that the required biochemical changes will happen as quickly as possible.

When the dough enters the prover, it will commonly be at temperatures of 25–32 °C (77–90 °F), which is the maximum at which most modern moulding equipment will work efficiently—any hotter and the dough will be so sticky that problems of product transfer will outweigh the advantage of any possible reductions in proof time. The dough expands by a factor of three or four during proving, to almost its final volume, and it is important that the skin remains flexible so that it does not tear as it expands. A flexible skin is one which has not been allowed to dry out, so that controlled humidity is essential. A humid atmosphere is also required to minimize weight loss during proving.

Yeast is at is most active at 40–45 °C (104–112 °F), so to minimize proof time, heat transfer to the dough is necessary, to raise its temperature typically by 10–15 °C (18–27 °F). Part of the heat is supplied as moisture condenses on the loaf surface and on the baking tin/tray, and gives up its latent heat. This quickly establishes a

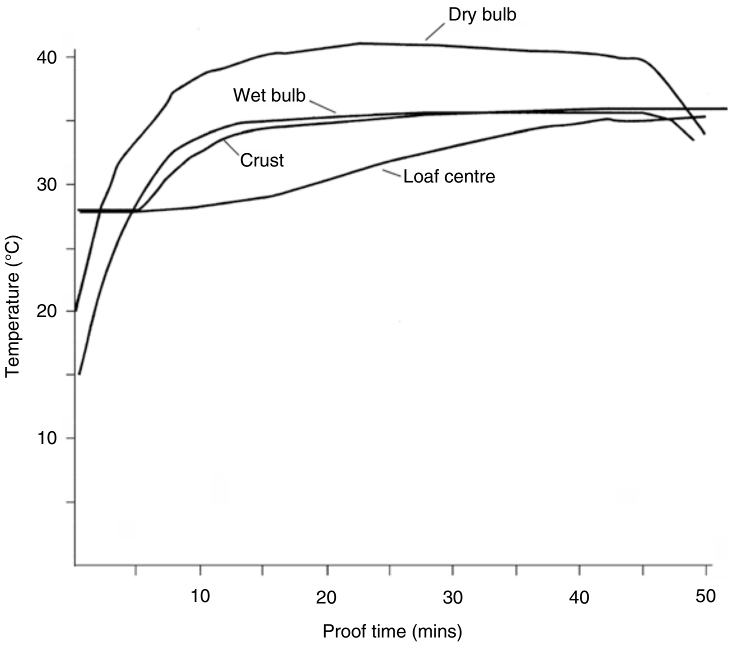


Fig. 5.6 Changes during proving

temperature gradient in the dough, which is the driving force for heat transfer, by conduction, to the centre of the dough piece. At this stage of the process the dough is dense and is a relatively good conductor, so the temperature of the dough piece will stabilize quite quickly.

A prover air inlet temperature of 42 °C (108 °F), with a dew point of 35 °C (95 °F), is typical. This warms the dough gently and after about 20 min the dough will be at a temperature of about 35 °C, the peak gassing temperature. The temperature of the dough stabilizes at the dew point temperature and further heat transfer evaporates moisture from the surface instead of raising the temperature. The evaporated moisture raises the specific humidity as the heat transfer reduces the dry bulb temperature, so that at the outlet the circulating air may be almost saturated. Typical air conditions and dough temperatures are shown in Fig. 5.6. The dough piece gains weight at the start of proving and then loses it again—the net loss on a dough piece weighing 880 g (31 oz) will be typically about 3 g.

Yeast Level, Proof Time and Prover Conditions

The expansion of dough during proof is largely controlled by the rate at which the carbon dioxide gas is generated within the dough. Only the weakest of doughs will actually leak gas during proof so that proof volume or height is often taken as the benchmark by which 'optimum' proof has been achieved. However, since the rate

Table 5.1 Example of the impact of proof temperature on proof time to constant dough volume

Prover temperature (°C)	Proof time (min)
24	200
30	140
40	60

at which heat is transferred to the dough is the main factor which controls carbon dioxide gas production by the yeast in the dough this means that final proof time will be very dependent on proof temperature and recipe yeast level. The data in Table 5.1 show an example of how the choice of final proof temperature affected the time required to achieve the same height of dough piece in the pan before baking. It is worth noting that the lower proof temperatures and therefore longer times involved, mean that the temperature differential between dough piece surface and centre is reduced. This usually leads to more uniform expansion in the oven but the penalty is that longer processing times (and larger rovers) are required.

It is inevitable that industrial bakers have sought opportunities to reduce process times with respect to proving. As noted above, the optimum temperature for yeast activity in gas production terms, is around 40–45 °C and so it is inevitable that attempts have been made to run proving commercially at as high temperatures as possible. Higher proof temperatures will warm the dough more quickly, but a steeper temperature gradient through the dough will certainly have an effect on product quality because it will result in uneven gas production rates and, ultimately, uneven cell structure and texture in the finished loaf. A further disadvantage of proving at higher temperatures is that it makes the effect of a plant stoppage much more dramatic. Although most provers have some extraction facility that can be used to bring down the temperature quickly when there is a plant stoppage, to give more time for the fault to be found and corrected without over-proving the dough that is already in the system, it is still a fact that the higher the operating temperature, the shorter this critical time will be. As so often in real processes, the requirements of economics and quality conflict and it is the job of the engineer and the baker to arrive at a sensible compromise.

The other way to reduce proof time is to start proving with the dough already at its optimum temperature of 35–40 °C. This has been done on an experimental basis both by using conventional make-up plant followed by a microwave pre-heater and by using special make-up plant which will handle dough that has been mixed to the required temperature. Microwave heating has also been applied to reduce the proof time of dough pieces. The most successful application of microwave heating was for proving doughnuts and similar fermented goods which do not require a pan. Schiffmann et al. (1971) claimed a reduction in final proof time from 45 to 4 min without loss of quality. However, while there have been several attempts to introduce microwave proving the adoption of the technology has been limited. In part this is associated with capital and operating costs. The shortening of final proof time through the application of radio-frequency may have potential. However at the time of writing successful approaches to reduce proof time without compromising product are limited.

Prover Operation and Design

Practical Proving

The prover air conditioning system has to be able to handle the full range of operational conditions. At one extreme will be the start-up on a cold morning, when the bakery and all the mixing and forming equipment are cold and, even if the prover inlet conditions are right, the average condition will be colder than standard because the heat load on the system is greater. It is normal practice under these conditions not only to raise the prover temperature for start-up, but also to increase the yeast level in the dough. This is a typical example of the pragmatic measures that are taken in production to maintain acceptable quality when a process solution, in this case providing a temperature-controlled dough-forming area, is available but could not be economically justified. At the other extreme are hot humid days when flour temperatures are high and hot tins are being returned to receive more dough pieces at the moulder The process is always the most demanding when the external circumstances make it most difficult for the prover air conditioning to respond. However, it will help to reduce yeast level and run the prover at a higher speed than normal, though such an approach cannot compensate for the potential loss of quality with scorch marks on the sides of baked loaves.

Prover Checklist

It is important that bakers understand how the air is supposed to circulate in their provers and how the air conditioning systems cope under different ambient situations. Then they are in a position to take regular readings and detect any deterioration in air quality before process performance starts to get worse. The minimum checklist should include air temperatures and humidities at entry and exit of the prover, as well as a velocity measurement to check that airflow is as it should be. To check uniformity it is best to compare proof height and centre temperature for loaves that have taken different paths through the prover. Many large plants now convey the products through the prover and oven in single file, often in a figure of eight, and this concept largely removes the possibility of differences in air flow, and therefore heat transfer, from one tin strap to the next, although badly designed tin straps can still cause loaf-to-loaf differences within a strap, especially if the design of the strapping is such that air cannot circulate between the pans. Finally, for each of their products bakers should record how the product looks, in terms of temperature and height in the tin, at convenient points in the prover. This knowledge will often allow them to take corrective action when something changes in the mixing room and they may be able to save loaves that would otherwise be out of specification.

Airflow

The air condition that the dough pieces encounter when they enter the prover must encourage condensation as an essential part of the process, but excessive condensation can lead to unsightly streaks or spots on the crust or excessive flow with free-standing products. Also, saturation of the air should be avoided since condensation is then likely to occur on the structural surfaces of the prover, which may lead to hygiene problems, or could cause corrosion in equipment which is not satisfactorily protected. These potential problems are avoided by minimizing the temperature drop between the air inlet and return, with the air approaching saturation as it leaves the prover. The temperature step is proportional to the heat transferred so a smaller step means that more air must be circulated in order to supply the required heat transfer to the dough. Higher air flows give the potential added advantage of more even side-to-side conditions and less danger of stagnation of air.

Ambient Conditions

There are other practical issues of prover design which need to be considered, particularly where ambient conditions can be hot and humid and air of the right quality is not available to be mixed or conditioned to produce air for the prover at the specified temperature and humidity. In the UK, air at 42 °C (108 °F) and 80 % relative humidity can always be provided by taking fresh air, passing it through heating coils and then adding steam to raise the humidity. Often, to improve thermodynamic efficiency, most of the air is re-circulated and only a proportion of fresh air is added, to return the inlet stream to its design condition. However, in hot climates the fresh air may be too hot to provide this function and extra air conditioning equipment must be used. If conditions are dry, as is often the case in the tropics at high altitude, water sprays can be supplied in the fresh air stream to cool the air as the water evaporates, as well as to provide the planned humidity level. If the ambient conditions are humid as well as hot, then refrigeration may have to be supplied so that the fresh, or the return, air can be cooled, in order to condense some of the moisture, and then reheated to the operating point. The process path on the psychrometric chart is shown in Fig. 5.7. The potential problem of an excessive heat load on the prover air conditioning system caused by hot tins returning from depanning can be economically averted by adding forced convection cooling on the return tin conveyor.

Mechanical Handling

As well as providing the right process conditions for the proving dough pieces, the prover must be capable of accepting tins at the specified plant rates, holding them for the proof time and delivering them to the oven (Fig. 5.8). Two configurations are

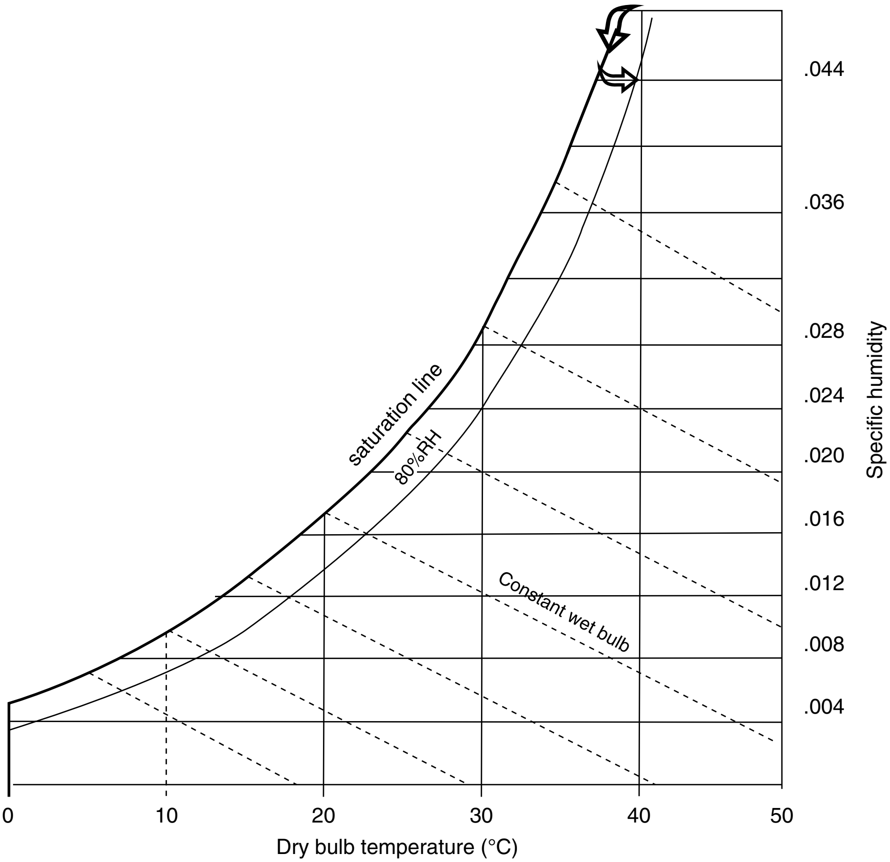


Fig. 5.7 Refrigerated proving in tropical climates

common, one where the tin straps are loaded on shelves in a carrier moving on a chain circuit, and the other where the straps are fed onto a continuous conveyor that carries them through the proving chamber in a spiral path: the construction principles a of the two types are shown in Figs. 5.9 and 5.10.

The transition from prover to oven is a critical phase in the breadmaking process Fig. 5.11). The dough is approaching the final loaf volume but is still a completely flexible structure, maintained only by the continuing production of gas within the semi-porous cells formed by the membranes of hydrated protein. The first essential is to protect the young loaf from physical damage because if gas bubble stability is poor, even quite small impacts can destroy the fragile structure. The structure can be particularly delicate in some circumstances, for instance if there are flour quality problems or if the dough is not correctly developed, and it is in these circumstances that the product handling system is really tested.

Fig. 5.8 Four-piece pan bread in the prover (courtesy Spooner Industries)

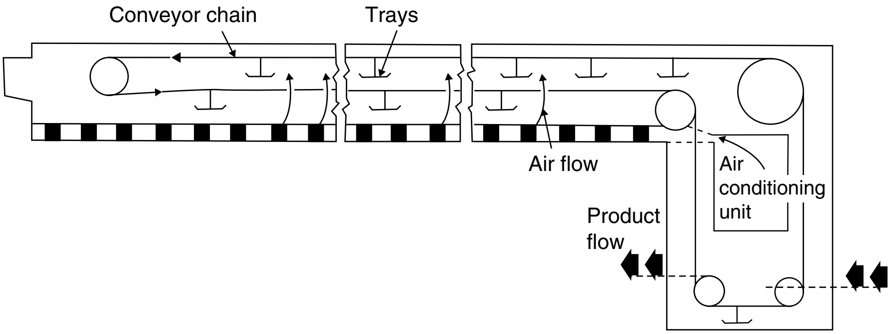


Fig. 5.9 Prover with carriers

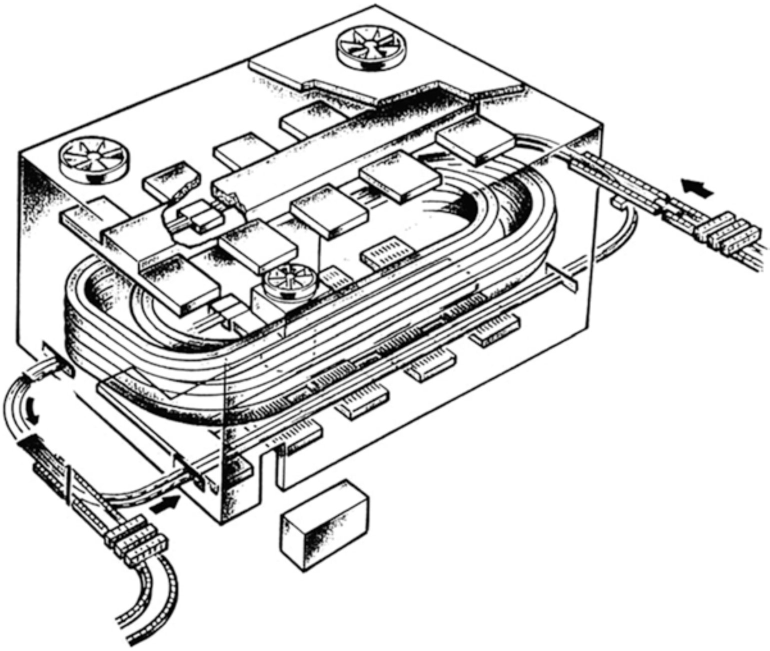


Fig. 5.10 Spiral prover

Fig. 5.11 Four-piece pan loaves entering the oven (courtesy Spooner Industries)

The Baking Process

Crumb Structure

For the centre of the dough piece, the move into the oven is undramatic. It is so well insulated by surrounding dough that it is completely insensitive to any change for the first several minutes of baking and continues at peak gas production. Effectively, the centre of the loaf gets additional proof time which compensates for its slower start at the beginning of proof. Eventually the centre of the loaf does start to warm up and as the temperature rises, it goes through a complex progression of physical, chemical and biochemical changes which are independent of the precise conditions in the oven and, therefore, outside the control of the oven operator.

Once the crust has formed it creates a physical barrier to further expansion of the dough piece. Where the dough piece is being baked in the pan the sides of the pan create a further barrier to expansion. The central portions of the dough pieces continue to expand in the early stages of baking and the crumb is forced outwards where it meets the crust and the pans. As a result of the expansion thin layers of crumb become compressed against the inner surfaces of the crust and there is a loss of cellular structure in these regions. Once the central crumb expansion has ceased the main features of the crumb cellular structure are in place. Coalescence of gas bubbles occurs while the dough is expanding and the crumb cell structure begins to form. Gas bubbles that started with sizes in the range 20–250 μm now coalesce to yield crumb cells of 1–4 mm.

Thermodynamically, the situation in the centre is fairly simple. The driving force for heat transfer is the temperature gradient from the region near the crust, where the temperature is limited to the boiling point of water, to the centre. The heat transfer mechanism is conduction along the cell walls and the centre temperature will rise independently of the oven temperature and approach boiling point asymptotically. There is no significant movement of moisture and the moisture content at the loaf centre will be more or less the same at the end of baking as it was at the beginning. Figure 5.12 shows the loaf core temperature (LCT) during baking for three different tin sizes—loaves with a smaller cross-sectional area will bake more quickly.

Yeast Activity and the Foam to Sponge Conversion

Yeast activity decreases as the dough warms beyond 45 °C and the yeast is inactivated by the time the temperature has reached 55 °C (131 °F). During this period there is a contribution by the yeast to oven spring. Typically only about 10 % of the oven spring can be attributed to the last of the yeast activity, around 35 % coming from the release of carbon dioxide from solution and the remaining 55 % from thermal gas expansion. Stability of the dough structure is maintained because the trapped gases expand as they warm and maintain the positive internal cell pressure.

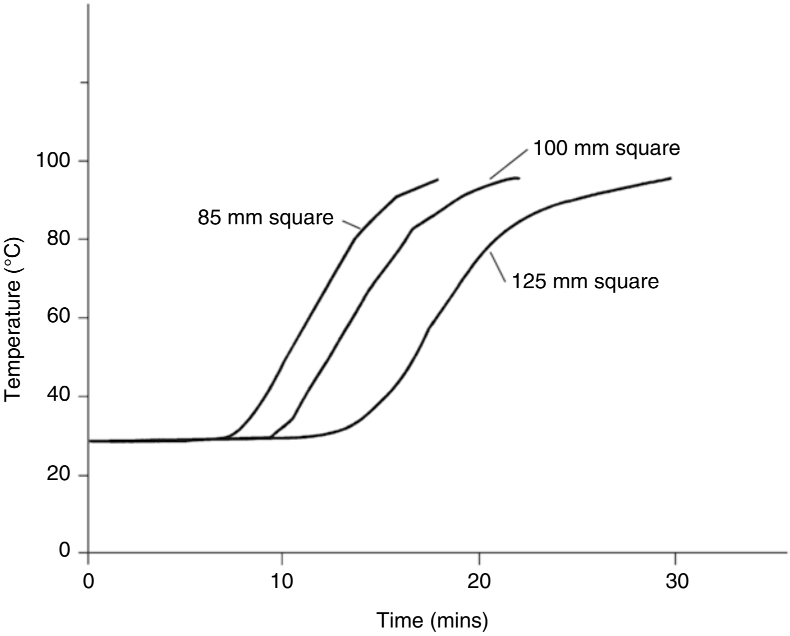


Fig. 5.12 Variation of loaf core temperature with time

As long as the gas cells remain intact the dough piece can expand but as the foam in the dough makes the transition to sponge in the baked product gas pressure becomes equalized and expansion ceases. The transition from foam to sponge takes places after the yeast has been inactivated with the precise point depending on a number of factors as discussed below.

Starch Gelatinization

Gelatinization of intact wheat starch granules starts at about 60 °C (140 °F) and initially the starch granules absorb any free water in the dough. The gelatinized starch will eventually be self-supporting and will take over from the protein membranes which, by their gas-retaining properties, have established the form of the loaf but have little intrinsic strength. There is insufficient water in the dough to gelatinize fully the starch, and water will transfer from the protein membranes to the starch as baking proceeds. Starch has remarkable water-retaining capacity and the ease with which gelatinization continues is affected both by starch damage, deliberately imparted during milling (Chap. 12) and by enzyme activity during baking. The precise temperature of gelatinization will be affected by the dough recipe. This is particularly important when sugar is present in the recipe since this has the effect of delaying the gelatinization of the starch by many degrees and in some cases may even prevent a complete foam to sponge conversion taking place. A late or incomplete foam to sponge conversion may be seen as sidewall collapse in pan loaves and in the sinking back and wrinkling sometimes seen with sugar containing fermented goods, e.g. soft rolls, fruit buns.

Enzyme Activity

Cereal *alpha*-amylase activity, which is largely responsible for converting starch into sugars, is at its maximum between 60 and 70 °C (140–158 °F) and the amylase is not completely destroyed until the temperature reaches 85 °C (185 °F). Insufficient amylase activity can restrict loaf volume, because the starch structure becomes rigid too soon, while too much activity, which may be the case after wet harvests, can cause the dough structure to become so fluid that the loaf collapses completely (Chap. 3). It is the timing and volatility of the complex interactions of gelatinization and enzyme activity that determine the quality of crumb in the finished loaf. It is worth reiterating that poor crumb quality is not a baking fault, it is caused by loss of control at an earlier stage in ingredient or dough preparation.

Baked Temperature

A key parameter of loaf quality that the oven operator must monitor is the final core temperature. The definition of 'baked' is an arbitrary one, often determined by the loaf's ability to withstand slicing after cooling, but a temperature in the order of 92–95 °C (198–203 °F) at the centre of the loaf at the end of baking is generally accepted as being necessary for the structure to be adequately rigid throughout the loaf, in part because of the loss of water. In most bread and fermented products the foam to sponge conversion will have taken place before the product reaches a core temperature of 92–95 °C (198–203 °F). This transition can be seen in the baking product when the height of the product falls slightly just before the end of baking (Cauvain and Chamberlain 1988). If the loaf is taken from the oven immediately that this point is reached it is usually too weak to support its own weight and so it appears that the continued loss of water contributes to the structural integrity of the product.

Crust Formation

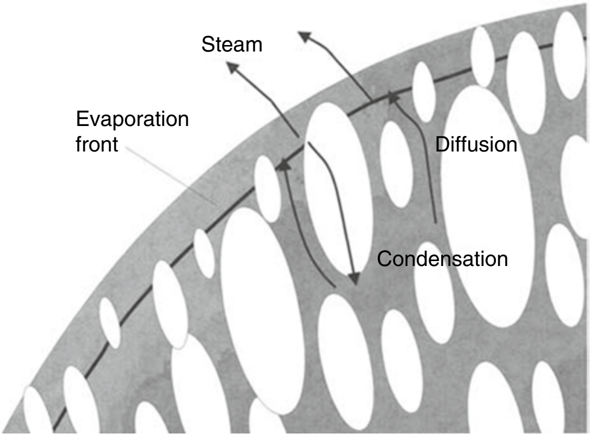
Formation of a satisfactory crust is one of the most important aspects of baking—the crust provides most of the strength of the finished loaf and the greater part of the flavour. The thickness and characteristics of the crust to a large extent define the product (Chap. 1). In contrast to the crumb, where changes during baking are largely chemical and biochemical, though initiated by the rising temperature, in the region of the crust very complicated physical mechanisms are at work. Condensation on the surface of the loaf at the start of baking is essential for the formation of gloss, but quite soon the temperature of the surface rises above the local dew point temperature and evaporation starts. Very soon after that the surface reaches the boiling point of the free liquid, which will be close to 100 °C (212 °F) and the rate of moisture loss accelerates. As the loaf surface dries, so the evaporation front moves below the surface and the crust of the loaf starts to form. It is important to understand that moisture loss, and therefore weight loss, is an essential part of crust formation, and although it is possible to manipulate oven conditions to reduce weight loss, the characteristics of the loaf, specifically the qualities of the crust, will also change. For a typical plant loaf, with a finished weight of 800 g (28 oz), the weight lost during baking will be 50–55 g (1.8 oz) and anything produced with more crust will inevitably have a higher weight loss.

The heat transfer mechanisms at the evaporation front are complex. As well as conduction within the cell walls, each cell acts rather like a heat pipe—water is evaporated at the hot end of the cell, some is lost to the outside but the rest moves across the cell, in the direction of the centre, and condenses at the cold end of the cell, transferring its latent heat before diffusing along the cell wall to evaporate again at the hot end. The evaporation front may develop more quickly at the top surface of an open-topped loaf, but it is present also on all the faces of the loaf. The tin, the supporting grid and any surrounding tins may shield the loaf from convection and radiation to some extent, and so slow down the formation of crust, but the presence of the impermeable tin surface does not prevent evaporation, the steam escaping freely from between the inside walls of the tin and the dough surface. The operation of the evaporation front is shown schematically in Fig. 5.13.

If the steam is not able to readily escape from between the dough piece and the pan then pockets of high pressure can build up and these may lead to ‘indents’ in the bottom and occasionally the side-wall crusts. Commonly the indented areas are pale in colour showing that these portions of the crust have not been in contact with the pan surfaces for long enough for them to assume the normal colour. This phenomenon has been referred to as ‘pan-lock’ by bakers (Cauvain and Young 2001) and its presence is exacerbated by strapping pans too close together or by placing individual pans too close together in the oven. Small venting holes placed at the angle of the side wall and base of the pan readily prevent this problem. Product baked in pans with slightly ribbed sides do not normally exhibit this problem. Oven bottom loaves and other fermented goods baked on trays do not normally exhibit this problem because the steam pressure is more readily dissipated.

Outside the evaporation front is the region that is called the crust and here the temperature continues to rise towards the oven air temperature. As it heats further, bound water will be driven off and the crust will acquire its characteristic crispness. Crust colour comes mainly from Maillard reactions (Perez-Locas and Yaylayan 2010) which start at temperatures above 115 °C. These reactions also produce bread flavour and the aromas of baking. The rate of formation of crust is approximately

Fig. 5.13 Heat transfer in the evaporation zone



linear, so that a loaf baked in 30 min may have a 3 mm (0.12 in) crust thickness, whereas a larger loaf that takes 50 min to bake will have a 5 mm thick crust. Cauvain and Young (2008) showed that an increase in crust thickness from 1 to 2 mm reduced the overall moisture content of an 800 g pan loaf by about 1 %, and so in sandwich breads which are expected to have a soft crust and moist crumb it is important to limit crust thickness.

The other contributor to crust formation is the continuing expansion of the inside of the loaf, caused first by the final burst of carbon dioxide production from yeast fermentation and then by the thermal expansion of the gases trapped in the cellular structure of the dough. The loaf, if it is in a tin, can only expand upwards. But the sides of the loaf have formed a thin crust and will not move, so cells just inside the crust, in fact those at the evaporation front, are subjected to shear and compression and become flattened and elongated. This effect is most obvious at the top edges of the loaf, where the displacement is greatest and where a split develops as the top crust lifts, exposing a band of elongated inner crust cells, called the ‘oven break’. Figure 5.5, which showed how the cells in the dough expand during proof, is magnified further in Fig. 5.14, to show how cells near the crust shear to give a compacted layer and expose the shredded oven break. Specific characteristics of the crust can be developed independently.

Gloss Formation

The first few seconds of baking are vital for the formation of a glossy crust on the loaf. Again it is a psychrometric problem. As it enters the oven, the surface of the loaf is exposed to high levels of radiation and, sometimes, convection and will increase in temperature very rapidly. To obtain gloss, it is essential that vapour condenses on the surface to form a starch paste that will gelatinize, form dextrins and

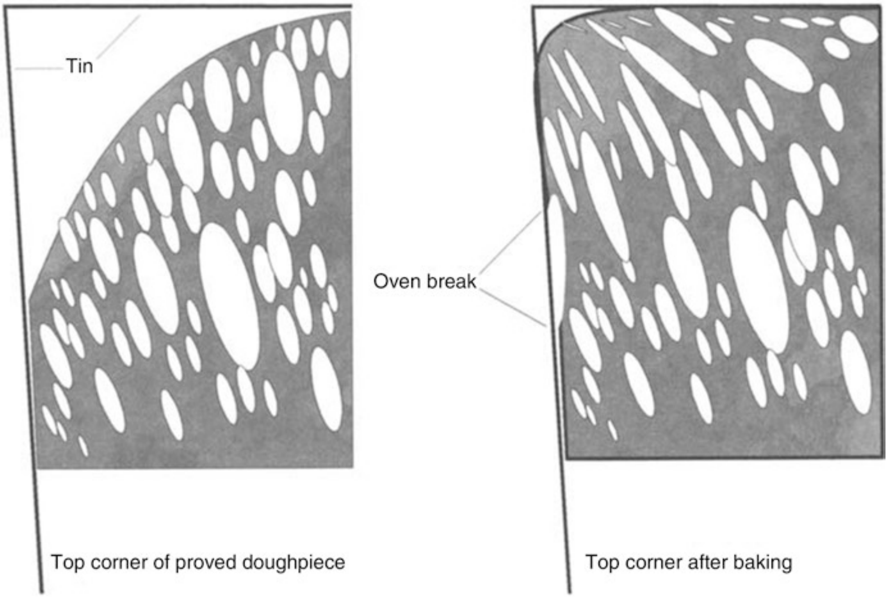


Fig. 5.14 Crust development and oven break

eventually caramelize to give both colour and shine. The pioneering experiments on gloss formation were conducted by Brown and Brownell (1941), and their results are still valuable to the oven designer today. They identified a difference in the way starch can gelatinize on the loaf crust. If there is excess water, paste-type gelation takes place; if the water availability is insufficient, then crumb-type gelation occurs.

The conditions necessary for a glossy crust are as follows:

- The dough must not be over-proved. If the dough has reached its maximum volume before leaving the prover, it will not develop satisfactory gloss.
- Paste-type gelation must take place before there is any chance of crumb-type gelation.
- A minimum oven temperature of 74 °C (165 °F) must be maintained for sufficient time (at this minimum temperature, the time required would be too long to be practically useful). In fact, the required time varies from 10 min at an oven temperature of 77 °C (171 °F) to only 15 s at 99 °C (210 °F).

The important condition of excess water on the crust will only happen when the crust temperature is below the dew point temperature of the oven atmosphere at the oven inlet. In practice, this means that, if the oven is at a typical temperature of, say, 225 °C (437 °F) the dew point temperature needs to be above 93 °C (199 °F) to ensure that the excess water condition is maintained for long enough. To guarantee suitable conditions usually requires a special inlet section on the oven, called a steam tunnel.

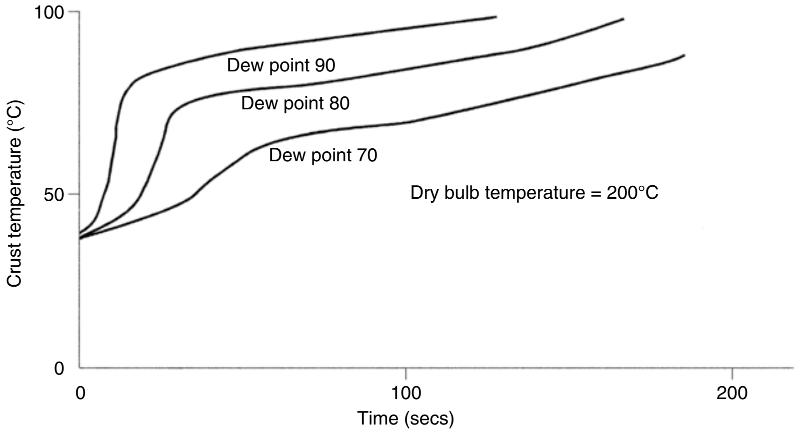


Fig. 5.15 Crust temperature against time for different dew point temperatures

The way in which crust temperature depends on dew point temperature is shown in Fig. 5.15, with only the top curve satisfying the conditions for high gloss. Notice how the rate of increase of the crust temperature levels out as it approaches the dew point temperature. This is the point where condensation changes to evaporation, and exactly how this happens will depend on the air velocity in the region. To make sure that all loaves are treated equally, steam tunnels usually have low air velocities, but this is not a necessary requirement for gloss, it just makes it easier to maintain a high dew point temperature.

Crust Crispness

The pattern of humidity during baking affects another important crust quality besides gloss. Sometimes a smooth, elastic crust is required that can be sliced without disintegrating, but at other times a brittle crust, which will form a mosaic of cracks when cooled, is the marketing specification. The behaviour of the crust will depend mainly on the thickness of the starch paste layer—the thicker the layer, the more likely it is to craze as it cools. This means that when a pliable and glossy crust is required, the conditions for gloss formation must be maintained for the minimum time necessary and thereafter the baking conditions must be comparatively dry. With some ovens (e.g. rack and deck ovens) crust crispness or hardness may be further encouraged by encouraging the venting of humidity close to the end of the baking cycle, i.e. by opening a damper. This type of procedure is commonly followed with hearth, free-standing and rustic breads.

Oven Break

The shredded band of exposed inner crust that develops during baking at the edges of the loaf, on the join between the top crust and the side crusts, is called the 'oven break'. Most products look best with a regular break some 20 mm (0.75 in) high, but sometimes less is required (e.g. in the manufacture of lidded sandwich breads) and it is important to understand which parameters can be used to control the break. The break will increase with volume increase in the oven, the so-called 'oven spring', and decrease with crust toughness. Oven spring depends to a large extent on the state of fermentation in the dough when it enters the oven. If fermentation is almost complete, in other words if all the sugars have been converted, then oven spring will be limited. If this point has not been reached, which could happen if not enough yeast has been used, or if the proof temperature is too low or the time too short, then oven spring will be greater and there is more chance of an excessive break, which can become what is colourfully described as a 'flying top' or 'capping' (see Fig. 1.9) In the case of hearth-style breads the same problem may show as ugly bursts through cuts or ragged breaks in the sides of the loaves (Cauvain and Young 2001).

One of the mysteries of baking is why the oven break forms in the part of the loaf that it does (Cauvain and Young 2009). There is no clear pattern to oven break from loaf to loaf from a given batch of dough. There is no doubt that the oven break is exploiting small (probably microscopic) variations in the dough structure of individual dough pieces. One factor which has been overlooked in understanding the physical manifestation of oven break has been the placing of the dough in the pan. In particular the positioning of the 'Swiss roll' or curl of the dough piece. Craft wisdom dictates that the 'seam' or trailing edge of the dough piece should be placed on the bottom of the pan or tray in order to obtain uniform expansion (Cauvain and Young 2009). In modern plant such precise positioning is seldom achieved. There is no doubt that the random positioning of dough pieces in modern production confounds the location of oven spring. There is considerable tension in the curled dough piece and there will be a tendency for the Swiss roll to try and uncurl in the early stages of baking. It is possible that it is the spatial positioning of the leading edge, the first part of the curl, which is responsible for the way in which oven break is manifest.

With many bread products oven break can be controlled by cutting or marking the surface. The act of cutting allows for the controlled release of tensions in the dough and in many cases the pattern of cutting has now become an integral part of final product quality and authenticity (Chap. 1). The increased surface area of dough so created by cutting increases the rate of transfer of heat transfer to the centre of the piece and adds to the development of top crust. It might also be argued that an increase in the ratio of crust to crumb in the baked product contributes to the perception of greater flavour in the baked product. On the negative side an increase in the surface area can lead to higher weight losses during baking and in turn, a less moist eating crumb. However, the majority of products which utilise surface cutting are hearth, free-standing and rustic breads and as such, are not expected to have a thin, soft crust and super soft crumb.

Practical Baking

It is important to check regularly that the heat transfer equipment is in good condition, but for an oven the measurements are more difficult to make than in a prover and may require specialized help, perhaps from the oven manufacturer. A regular flue gas analysis is the simplest way of monitoring the condition of the combustion equipment, while measurements of air temperature and humidity in each oven zone for each product should also be recorded and checked regularly. The best confirmation that all is well is provided by quality control checks on the products themselves, and the most important reading is core temperature at the end of baking. When establishing a quality control procedure to monitor centre loaf temperature, it is important to remember that, just as there is a lag at the start of baking, so the temperature at the loaf centre will continue to rise for several minutes after the loaf has come out of the oven. No oven gives perfectly uniform baking and in some ovens there will be significant differences in temperature depending on position in the oven. The control procedure reflects changes with time and must not be confused with information reflecting unevenness in the oven. Thus it is important to understand the particular oven and always to take samples from the coolest position. The position of the loaf within a tin strap can also affect the heat transfer rates. To be on the safe side, the sample should always be taken from the centre of the strap.

Pan Strapping

As with all baking systems, in order to obtain optimum results it is important to design the tins and tin straps to suit the heat transfer capabilities of the oven. Compact straps may increase oven loading, but the overall profitability of the line also depends on loaf-to-loaf variations in centre temperature (and therefore weight loss) and a strap with narrow air passages between tins may cause significant weight loss variations between the end loaves in the strap and those at the centre. Most tins are made from steel, usually 0.8 mm thick with a non-stick coating, but baking time can be reduced by using black anodized aluminium, with the penalty that it is less robust and will not last as long in an automatic handling system.

Narrow straps between pans reduce the air flow and the rate of heat transfer in all ovens. The slower transfer of heat allows yeast to continue working longer in the early stages of baking. In effect this means that the some of the loaves, usually the ones in the centre of the strap, get extra proof. In such circumstances loaves may touch one another during baking and prevent the formation of a crust on the sides of the loaf, see Fig. 5.16. Similar problems may be encountered with crusty baguette baked in unsuitable slings and with bloomers and crusty rolls not spaced far enough apart on trays. The areas of the product without adequate crust formation are weak points in the product structure and contribute to more rapid loss of the crisp crust which characterises oven-bottom and hearth breads.

Fig. 5.16 Closely strapped bread pans

Oven Design

As with provers, one change in plant bakeries in recent years has been away from tunnel ovens towards the single-file conveyorized spiral oven. The simplicity of the concept improves reliability and uniformity of bake while the small inlet and outlet ports, together with the low thermal mass of the conveyor, lead to useful increases in thermal efficiency. An indirect-fired conveyorized oven is shown schematically in Fig. 5.17. The trend is to design for radiating surfaces in the oven to be cooler than used to be the case and to rely on forced convection for a higher percentage of the required heat transfer. This tends to reduce the thermal mass of the oven so that it warms up more quickly and can handle product changes and gaps in production more easily. Baking by convection also results in a more even surface colour than by radiation because the latter possesses the destabilizing characteristic of being absorbed more readily by darker surfaces. In other words, radiation will accentuate contrasts. It is interesting that there has also been a trend towards convection in biscuit ovens over the last 30–40 years, but there are now signs of the pendulum swinging back, as the required textural and colour-related properties for some products can only be obtained by increasing the radiative component of the heat transfer. As with proving, most of the developments in baking technology have been incremental in nature and have been related to increasing plant output, reducing product variability and improving mechanical, reliability (Fig. 5.18).

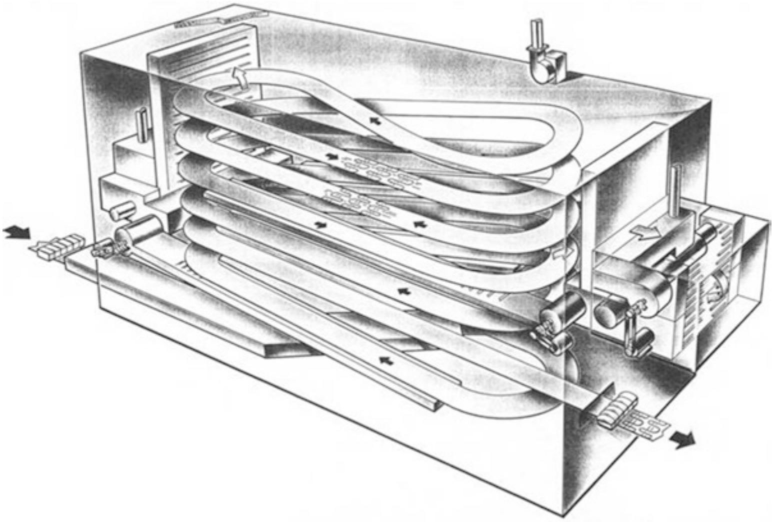


Fig. 5.17 Conveyorized oven

Fig. 5.18 Oven (courtesy Mecatherm)

Three technologies that are proven experimentally but not commonly implemented commercially offer the potential for markedly reducing baking times. One is dielectric heating (Ovadia 1994), using either radio frequency or microwave power (Schiffmann 1993), where the energy is supplied through the bulk of the dough piece, and it is therefore not surprising that baking times can be halved. The volumetric transfer of energy will not give rise to an evaporation front in the same way as conventional baking, so any crust formed will be thin and delicate, nor will the skin temperatures reached be high enough to generate colour and flavour in the crust. Invisible or crustless breads manufactured using microwave baking have begun to reach the market recently (Anon 2009). The market sector for bread sold without crust is significant in many parts of the world. A common approach is to remove the crusts (using them for other purposes such as bread crumb) and since this makes them more susceptible to mould growth because of the higher water activity of the crumb special wrapping and sterilisation techniques need to be employed (see Chap. 10). The advantage of the invisible crust loaf is that a hard, coloured crust is not formed and its removal is not required for those market sectors where the presence of the crust is not favoured.

One technique uses infrared radiators to increase heat transfer to the loaves. Again, marked reductions in baking time are recorded, but for this technology, where penetration of energy into the loaf surface is shallow, the result is less easy to explain. It seems possible that the crust region, outside the evaporation front, is the heat transfer bottleneck during conventional baking and that the limited penetration (<1 mm) of infrared radiation can overcome this barrier and increase the vigour of the heat pipe mechanism proposed for the evaporation front. Thus although the temperature driving force to heat the crumb is unchanged, this second mechanism increases the heat transfer and rate of temperature rise of the loaf core.

Another innovation uses high-velocity convection to improve the rate of heat transfer to the products. The main effect is in the warming-up phase, where baking time is saved by warming up the tin and dough surface more quickly than in a conventional oven and as much heat as possible is transferred while the conductivity of the dough is still relatively high. Such a process is described in an RHM patent (1989), where one embodiment, by way of example, specifies, for the first 10 % of the oven length, air nozzle velocities of 25 m/s (82 ft/s) and a temperature of 375 °C (707 °F).

All these developments are designed to reduce baking time, but they will also have an effect on the interaction of the mechanisms at work during baking and will inevitably change the characteristics of the final loaf. Relatively small reductions in baking time may be very valuable if they allow existing plant to be uprated, but when it is a question of specifying new equipment for a particular output, it is usually more cost effective to use conventional technology in an oven of the appropriate size than to save space by incorporating components to enhance the heat transfer.

Oven to Cooler

As noted earlier, baking and cooling overlap; cooling starts before baking has finished. As soon as the bread reaches the exit of the oven the air temperature will fall below the crust temperature. But the evaporation zone is still operating and the loaf centre is temporarily unaware of the changing outside environment. There is still a temperature gradient and it will continue to get hotter in the centre of the product for some minutes after it has left the oven.

De-panning is usually the next step and this is an operation that can become very difficult if the mixing, forming, proving and baking have not been properly controlled.

Faults that cause problems include:

- Under-proofed bread that has too much oven spring and such a dislocation around the top crust that the whole top crust comes off under suction;
- Over-proved bread that may have a very weak structure or may be too tall to fit under the suction head;
- Under-baked bread that may collapse or tear;
- Sticking of some of the loaves in the tins, possibly caused by erratic tin greasing.

Cooling continues as the bread is de-panned and transferred to the cooler. During all this time it is in an uncontrolled atmosphere and as well as losing heat, it is rapidly losing moisture. Whilst in the oven, moisture loss is an essential part of crust formation, but once out, any loss is wasted profit where bread is sold by weight and the loaves should be transferred as quickly as possible to the controlled conditions in the cooler. It can easily take 3 min to move a loaf from oven to cooler, and in that time it can lose 12 g (about 0.5 oz). Thinking negatively, this represents 12 g given away unnecessarily, but from a positive viewpoint, evaporating 12 g of water has cooled the loaf significantly and reduced the heat load on the cooler by about one-fifth.

The Cooling Process

There are two distinct mechanisms involved in cooling a loaf. The first is by heat transfer, mainly by convection to the surrounding air, but also by radiation and conduction to the structure of the cooler. The second is by evaporation—moisture evaporates from the crust and the energy to evaporate it is drawn from the crumb. Typically, an 800 g loaf will lose 20–25 g (about 1 oz) during cooling, which, with the weight it has lost in the transfer from oven to cooler, represents about half the load required to cool the loaf to 25 °C (77 °F). This is illustrated schematically in Fig. 5.19.

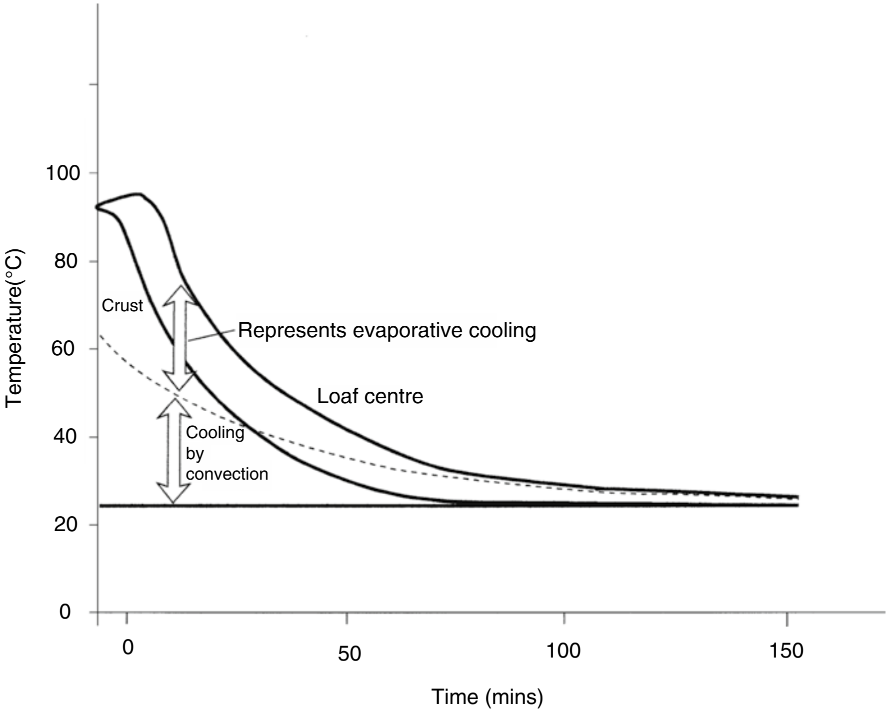


Fig. 5.19 The cooling process

It would be quite possible to design a cooler where the evaporation loss was much lower, for instance by having many small, independent cooling zones fed with cold saturated air, but the cooling times would be longer, because most of the heat would have to be removed by convection, and the capital and maintenance costs would be much higher. In practice the most common solution, combining an economic capital installation with a reduced evaporation loss is to have the section where the bread enters the cooler as cold as possible without refrigeration [with air velocities in the region of 1 m/s (about 3 ft/s), an air temperature of 20 °C (68 °F) and a relative humidity of 80 %], causing the crust temperature to drop so quickly that the crust will act as a barrier to further moisture loss. In countries where summer ambient conditions are hot, refrigeration will be necessary to obtain reasonable cooling times combined with low weight loss. Once refrigeration has been decided upon, however, it is worth installing sufficient capacity to run the inlet section of the cooler at 5 °C (41 °F). The initial rapid cooling rate will save another 3–4 g of moisture loss compared with typical, non-refrigerated cooling conditions.

Practical Cooling

Many coolers have no refrigeration and rely on using more fresh air in summer than in winter to maintain constant cooling conditions. The dampers that control the air flow are usually fairly simple, but there may be manual balancing adjustments, and it is important to check that airflow, as well as temperature and humidity, are maintained over the whole operating range. Understanding the cooler and keeping it in good condition is every bit as important as it is for the oven and prover, and a continuous record of temperature and humidity near the beginning and near the end of the product path provides a valuable check, providing the humidity instrumentation is regularly calibrated. Regular cleaning is vital, not only for hygienic reasons, but also to maintain performance, which could be seriously compromised by a furred spray nozzle or blocked filter.

Uniformity of cooling and weight loss is just as important as absolute performance. If the loaves are at different temperatures, the warmer ones will tend to get squashed in the slicers, and weight loss variability directly affects the target dough piece scaling weight. The target temperature for the centre of the cooled loaf will be about 25 °C (77 °F) for a sandwich loaf that is sliced on a reciprocating slicer, but if the recipe contains more fat, as in America for example, or if band slicers are installed, then satisfactory slicing will be practicable at higher core temperatures and cooling capacity can be saved. Temperatures should be recorded regularly, using the principles described in the baking section, but two techniques are necessary to check the weight loss performance. Regular, planned sampling, which is non-invasive and therefore does not create scrap, will allow the weight variance for the plant to be calculated and by subtracting the variance obtained at the end of the oven, a figure for cooler variance can be found. The variance is found by summing the squares of the weight differences from the average and dividing the total by one less than the number of readings. Variances can be subtracted—standard deviations cannot! The definition of variance mathematically is:

$$\text{variance} = \Sigma\left(x - \bar{x}\right)^2 / \left(n - 1\right)$$

where x is the measured variable, $\bar{x}$ is the mean, n is the number of readings and Σ stands for the sum of the differences between the measured variable and the mean.

If there is any sign that cooler variance is increasing, it will be necessary to conduct detailed tests by weighing loaves into the cooler, marking them and weighing them again when they come out. Remember that the loaves are losing weight at their maximum rate on the cooler in-feed, so the initial weighing and marking must be done without upsetting the normal loading progression.

Cooler Design

Just as tunnel ovens and tray provers in plant bakeries are being superseded by systems that use a conveyor that is only one tin strap wide, so rack coolers, where the bread is loaded onto shelves within a rack which is indexed along the top of the cooler then lowered and returned along the bottom, are being replaced with spiral designs. In fact the technology was born in the refrigeration sector, where the first spiral coolers were built in the 1960s and, because the concept is mechanically simple and inherently subjects all the products to the same processing cycle, it has migrated to proving and baking equipment also. The conveyorized designs have the added advantage that they are generally much easier to clean and access to the air conditioning equipment is better.

As already discussed, conventional bread cooling is by convective heat transfer and evaporative cooling, with the balance slightly in favour of convection. Process development is active at the two extremes, tilting the balance one way or the other. On the one hand, improvements to the distribution of the air and the control of its condition can further reduce weight loss by minimizing evaporation and, at the other end of the spectrum, most of the heat can deliberately be removed by evaporation, by using a vacuum cooler.

In the past two patents describing ways of improving the condition of the air have been granted to (RHM, (1988); and Allied Bakeries (1986). The first describes a spiral cooler with multiple zones with successive zones fed from alternate sides of the conveyor, a scheme that allows the contacting air to be maintained at low temperature and high humidity. The second patent describes another method of maintaining the circulating air in peak condition by spraying water onto the surface of the loaves in measured quantities so that it all evaporates before impregnating the crust. In other words, the air is continuously conditioned in the cooling chamber itself. The limitations of this method can be calculated directly from the psychrometric chart.

Vacuum cooling is invariably done as a batch process; bread is loaded into a vacuum chamber, which is sealed and partially evacuated. As the pressure falls, so there is a fall in the temperature at which the free water in the loaf boils, and the latent heat for the evaporation is extracted from the loaf, cooling it to slicing temperature in as little as 3 min, as shown in Fig. 5.20. In practice, the operation is quite sophisticated and the vacuum curve is modified to produce the particular product characteristics that are required. The process has been particularly successful on products where the crust is an important part of the structure, crusty rolls and croissants and on products which are very delicate, difficult to handle in the warm state, such as malt bread or panettoni, and prone to collapse (Brown 1993). Using part-baked products final oven baking and vacuum cooling have been combined to permit the rapid provision of final products in in-store bakeries (Anon 2008).

Two of the less obvious advantages of vacuum cooling are that it is relatively easy to maintain sterile conditions and thus gain a little extra product mould-free shelf-life, which can be critical in countries with extended distribution systems, and

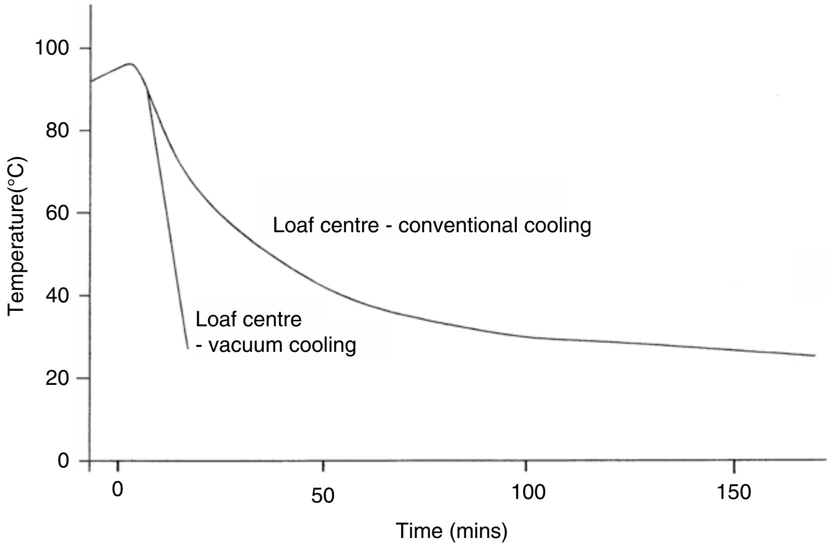


Fig. 5.20 Loaf cooling in a vacuum

it is also possible to reduce baking times, often increasing output by as much as 10 %. The reduction in baking time is possible because the loaf centre temperature which satisfies our condition for structure stability is less when the product is vacuum cooled—the speed of cooling, combined with the rapid expansion of the gases within the loaf throughout the cooling period, ensures that the loaf sets at its maximum volume and does not shrink or collapse. There are claims that vacuum cooling uses around only 10 % of the energy associated with conventional cooling (Anon 2013). The disadvantages of vacuum cooling are the high capital cost of the equipment and the high losses of moisture and the volatile fraction, although the latter can be partially compensated for by reducing the baking time and by introducing a pre-cooling stage to reduce the crust temperature rapidly before applying the vacuum. With larger products (e.g. pan loaves) the application of vacuum cooling can result in a change in crust texture such that when sliced there is a significant increase in the amount of crust dust that is generated.

Part-Baked Processes

Part-baked bread is a major sector for the baking industry, not so much for products for finishing at home, but for products that can be distributed for final baking at the point of sale. The system combines the economies of scale available where the part-baked loaves are manufactured with the flexibility and freshness obtained by finally baking to satisfy current demand.

In mainland Europe most of the intermediate products are frozen for distribution, often using conventional spiral freezers that have not been specially developed for the bakery industry. This can mean that weight loss is not minimized, and this directly results in problems of icing on the refrigeration coils. The technology has the fundamental cost burden that energy has to be expended to freeze each loaf and then again to thaw it.

The Milton Keynes Process, used vacuum cooling after a slow bake to stabilize the intermediate product. The loaves were distributed and stored in ambient conditions and then be finish baked at the point of sale (Chap. 9). The Milton Keynes Process as such is no longer but several similar approaches have been used by specialist manufacturers to supply ambient stored, part-baked products for bake-off. Typically such products are described as '80 or 90 % baked' before delivery to the end user.

Process Economics

Energy Usage

A major challenge facing all bread bakeries is the need to manage and minimize the energy costs involved. This is not an easy operation as baking is an energy hungry business with in many cases, a number of conflicting factors to take into account. Energy use is naturally associated with the initial mixing process where the transfer of energy to the dough by mixing is an integral part of gluten formation. Even if the dough is to be 'matured' using bulk fermentation (Chap. 2) then mechanical mixing is used in all but the smallest craft or artisan bakeries. With the transfer of energy during mixing comes the inevitable rise in final dough temperature. As discussed above (Chap. 4) ice may be added to the mixing chamber or a cooling jacket fitted to the mixer. Both approaches to limiting final dough temperature require the use of energy to achieve the desired dough cooling effect. In the case of ice, the energy is required to chill a brine solution, while with coolant has to be cooled in the case of a jacketed mixer. This explains in part, the interest in low energy mixing with transfer of energy by sheeting (Chap. 4).

However, the major part of energy usage in the bakery is associated with the heating and cooling processes of proving, baking and cooling (ETSU 2002) with by far the greatest proportion of heat being associated with the baking process itself (Fig. 5.21). The actual heat needed to convert dough into bread (proving and baking) is relatively small and has been estimated to be as low as 300 kJ/loaf (T. Fearn, *pers comm*) with data for energy usage in the oven lying in the range 570–1000 kJ/loaf depending on the design and operation of the oven. Based on such data this suggests oven efficiencies in the region 30–50 %. A major part of the 'missing' heat will be associated with losses vented from the oven to the atmosphere and some carried out of the oven by the 'hot' pans to evaporate into the bakery. Clearly there are opportunities for reducing such losses and significant changes in oven design are aimed at re-using the 'waste' heat. This is not always easy to achieve because along

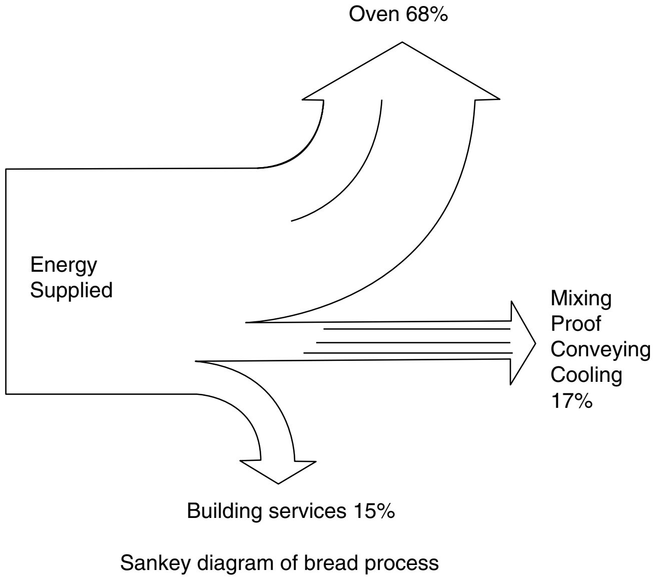


Fig. 5.21 Sankey diagram of energy usage in a typical plant bakery

with the water vapour released from the bread there are traces of fats and volatile materials which may foul heat exchangers and interact with the materials from which they are constructed.

Weight Loss

Weight loss at all stages, proving, baking and cooling is an important parameter affecting the economics of plant operation. This is particularly true in countries where bread is sold by finished weight and in countries where there is a specified maximum water content or in other countries where there is minimum solids legislation. Under this sort of legislation, if giveaway is to be minimized, weight loss must be tightly controlled. Minimization of weight loss is less critical in those countries which sell on a dry weight basis, but uniformity is still important as a quality parameter, as moisture content will affect both eating qualities and shelf life. Typical commercial figures for each stage of the process are given in Fig. 5.22.

Life Cycle Costs

Life cycle costing (LCC) is an industrial management technique, aiming to:

- Provide a comprehensive understanding of the total commitment of asset ownership;

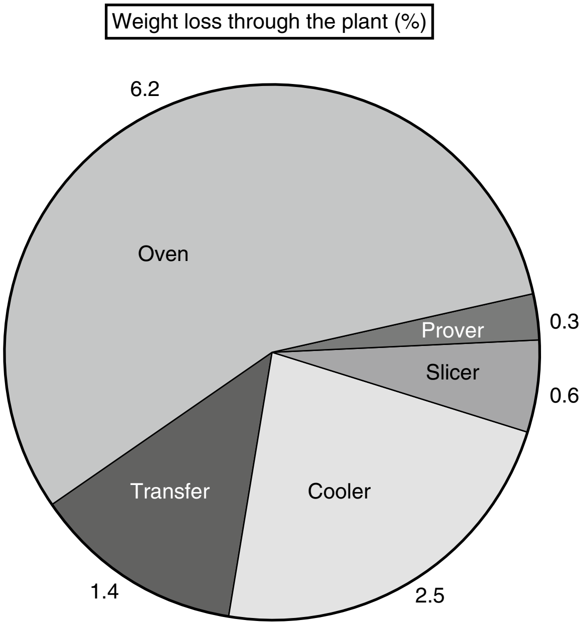


Fig. 5.22 Weight loss during processing

- Identify areas where improvement can be achieved through redesign or reallocation of resources;
- Improve profitability and increase industrial efficiency.

The practice is not widespread in the bakery world. The methodology for life cycle costing was standardized in IEC (TC56) (1996), which puts costs into perspective by modelling the total cost of operating a process plant for the whole of its planned life. It is particularly valuable when new equipment is being considered, when quite a small change in specification can yield huge savings during the life of the plant, but unless data are collected in a useful format during normal bakery operation, the costing model will be based on conjecture rather than fact. For instance, some bakeries regard maintenance and cleaning as overhead charges and this makes it impossible to justify extra capital investment that might reduce maintenance requirements or make cleaning easier. The life cycle cost approach also forces the equipment supplier and the user to work closely together, ensuring that the supplier fully understands all the operational implications of design decisions. By specifying performance guarantees in terms of the model for life cycle costs, the supplier is committed to a realistic initial model and the user is much better placed to make the investment decisions that will maximize profitability.

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Chapter 6
Dough Retarding and Freezing

Introduction

Over the years bakers have sought ways to extend the working life of dough, which is otherwise largely limited by the natural processes of yeast fermentation, enzymic activity and structural relaxation of the gluten. Improvements in production efficiency have been the main driving force for the baker to seek such extensions in dough life. For example, some products are required in small numbers, which necessitates mixing small batches of dough, but maximum production efficiency is more often achieved by producing larger quantities of dough than those needed for a single day's product sales. Other driving forces for extending dough shelf life have included the avoidance of unsocial working hours and local restrictions on night baking.

Since yeast fermentation is significantly slowed down by lowering the dough temperature, it was only natural that attention would be focused on the application of refrigerated and deep-freeze temperatures to yeasted doughs. If the dough temperature is reduced low enough yeast fermentation will cease altogether and the dough can be held in what approximates to a state of suspension. Early experiments with the refrigeration of yeasted doughs were to lead eventually to the development of the process which has become known as 'dough retarding' and which utilizes specialist refrigeration equipment. There are both similarities and significant differences between retarded and frozen doughs. They share the common problems associated with the poor conductivity of dough but require quite different equipment if both processes are to run under optimized conditions.

Retarding and deep freezing of yeasted doughs are not necessarily the 'convenience' products that they are sometimes claimed to be. For example, the early introduction of retarding and deep freezing techniques into UK craft bakeries during the 1950s met with some success but gradually the limitations of the technology and the equipment reduced their impact on the baking industry. The evolution of the 'in-store' bakery resulted in a revival of interest in retarded doughs in the UK. In other European countries the use of retarders has remained more common

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since their introduction, perhaps in part because of the continued survival of large numbers of small, craft bakers where there are limitations on working practices, or where the retarding process is seen to be making a positive contribution to product quality.

The production of frozen doughs had less appeal to the craft baker and was more suited to centralized production of the frozen units, with distribution to satellite storage and bake-off. The popularity of frozen dough products has always been less in Europe than that in the USA, where there are significant numbers of bake-off units using frozen dough technology (Best 1995). With improvements in technical understanding and process control, the use of frozen dough in Europe has increased.

Retarding[1] Fermented Doughs

Most fermented goods can be produced successfully via retarded dough, provided that retarding and proving conditions are chosen to suit the product type. As discussed in more detail in the section on freezing, dough is a relatively poor conductor of heat and in consequence products having a large radius, such as pan bread dough pieces, will take longer to cool and warm than those with a small radius, such as French sticks and rolls. Further, dough pieces with large radii are much more likely to cool, or warm, with larger temperature differentials between the centre and surface of a piece of dough, which are likely to have an adverse effect on final product quality. Therefore the range of conditions that can be used to produce acceptable bread is less than for smaller fermented goods so that if retarders or retarder–provers are to be used for mixed large and small goods production, the conditions in the units should be set to achieve optimum large-bread quality.

Suitability of Breadmaking Processes

All the major breadmaking processes described in Chap. 2 may be used for producing dough intended for retarding, though the most suitable are those which are based on no-time breadmaking processes. The process of retarding dough will not improve the overall product quality, so the recipe used, the choice of improver and processing conditions must be compatible with the breadmaking process chosen. Breadmaking processes which use periods of bulk fermentation as a major part of the dough development mechanism are least suited to retarding for two main reasons. First, the level of yeast in the recipe is an integral part of dough development so that any changes in yeast level for purposes described later would require compensatory changes in bulk fermentation time or dough temperature, or both. Second, the greater quantity of gas present in bulk-fermented doughs as they enter the

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[1] To avoid unnecessary repetition the term ‘retarding’ will refer to the cooling process which takes place in both ‘retarders’ and ‘retarder–provers’ so that references to retarders should be taken to include retarder–provers, and vice versa, unless specified otherwise.

retarder may have an adverse effect on final product quality. Sponge and dough breadmaking processes may be used to produce doughs for retarding, the best results being obtained if no bulk fermentation time is given after the sponge has been mixed into the final dough. Under most retarding temperatures fermentation continues, albeit at a low rate. Using sponge and dough processes in such circumstances may raise the ‘acid’ flavour of the baked product to an unacceptably high level and will require adjustment of the sponge conditions.

No significant changes are necessary to the mixing or processing conditions used with short or no-time breadmaking processes. It is unnecessary to lower the final dough temperatures, although this practice is often used as a means of reducing yeast fermentation before and during the early stages of retarding. However, it is not recommended, especially in breadmaking processes where improvers are a necessary part of dough development since lowering of the dough temperature will reduce the contribution of any oxidizing agents and enzymes present and may lead to problems associated with lack of gas retention in the dough, such as loss of product volume and white spot formation (see below).

As a general principle doughs should be processed and loaded into the retarding unit as quickly as possible in order to avoid excessive gas production and any losses of quality which may arise from undue delays. This requirement for minimizing delays before the dough enters the retarder must be balanced against the practical requirements of the bakery. For instance, it may take some time for the bulk of the dough from the mixer to be divided and processed. The length of this operation will depend, in part, on the size of mixing that has been produced. As a general rule delays greater than 20 and certainly 30 min should be avoided. It may be necessary to mix smaller quantities of dough than normal in order to achieve more rapid processing for retarding.

The frequency with which processed dough batches are transferred to the retarder also requires some control, otherwise frequent opening of the retarder doors will continually raise the temperature in the retarder and reduce its effectiveness in cooling the dough pieces. Rapid chilling of the dough pieces is necessary if gas production in the retarding phase is to be minimized and is especially important with dough pieces of larger radius. Each time the retarder door is opened there will be an exchange of air with the bakery atmosphere. The air in the retarder will commonly have a higher relatively humidity than that of the bakery and so there is a tendency for the relative humidity to fall. This exchange will increase the risk of dough pieces ‘skinning’. Similar problems will be encountered if the retarder is only partly loaded. The relationship between products and retarder relative humidity is discussed further below.

Recipe and Yeast Level

When deciding on a recipe to use for retarded doughs it is essential to choose one which will give products of acceptable quality in fresh production. Usually the only change in dough recipe required for retarding is to adjust the yeast level, the degree of adjustment depending on the process and equipment being used. With no-time doughmaking processes the adjustment of yeast level is not a problem since it is relatively easy to adjust subsequent proof temperatures, times or both. However, with bulk fermentation processes, changes in yeast level will affect the balance between yeast quantity, dough temperature and bulk fermentation time which is required in order to achieve optimum dough development. For example, if yeast levels were to decrease, it would be necessary to combat the under-fermentation which would arise by a simultaneous lengthening of the bulk fermentation period, or an increase in bulk dough temperature, or both. As a general rule, raising the dough temperature by 2 °C will require a compensatory decrease of about 25 % of the current yeast level; this alteration will slow down the rate at which the dough proves after retarding.

The choice of yeast level in retarded doughs is intimately linked with dough piece size, storage temperature and time, proving conditions and, of course, the desired product quality. There are such a large number of potential combinations of these factors that it is not possible to set down precise rules for adjusting the yeast level in retarded doughs. The choice of level also depends on whether the baker is using a separate retarder and prover or a combined retarder-prover. In the former case the practice is often to keep yeast at the same levels as for scratch production, or even to increase yeast levels so that when the colder than normal dough enters the prover, final proof times remain conveniently short. Such practices limit the types of products which can be successfully retarded to those of small radius or with higher levels of enrichment. The automatic control on retarder–provers (see below) allows for greater flexibility and choice of retarding and proving conditions. In such cases a wider range of products can be made and product quality can be more closely controlled. When using retarder–provers it has become common practice to reduce yeast levels, especially with larger dough pieces, to avoid losses in quality associated with ‘skinning’ and ‘white spots’.

The relative humidity (RH) of the dough when it first enters the retarder is much higher than that of the air in the retarder. Typically the equilibrium RH of the dough is between 90 and 95 % (equivalent to water activities of between 0.90 and 0.95) and the RH of the air around 60 %. During the early stages of retarding the dough loses moisture from its surface as it tries to achieve equilibrium with the air surrounding it. The cooling coil in the retarder is designed to maintain as high an RH as possible, but the dough pieces will progressively lose moisture during storage as shown by the example for 60 g (2 oz) rolls illustrated in Fig. 6.1. The overall weight loss from a dough piece during retarded storage is directly affected by the yeast level and is greater with increasing yeast level. The more moisture that is lost from the dough piece, the greater is the risk of the formation of the dry surface which bakers call skinning. The precise mechanism of the formation of this skin is not fully understood but the phenomenon is largely irreversible.

The potential for greater weight losses from retarded doughs with higher yeast levels is due in part to the greater expansion and accompanying increase in the surface area of the dough piece. An example of this effect is illustrated in Fig. 6.2 where the volume of 60 g dough pieces made with four different yeast levels

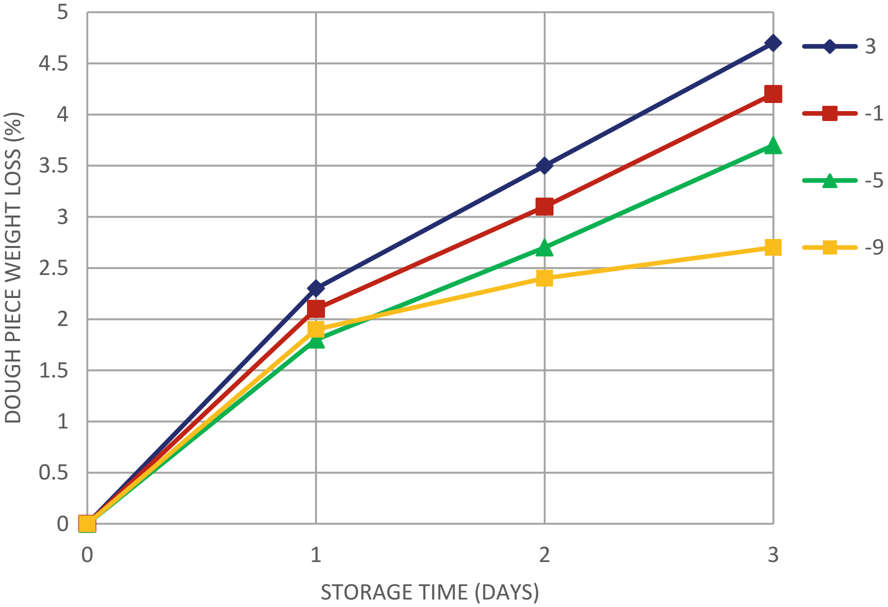


Fig. 6.1 Effect of storage time and temperature (°C) on weight loss from 60 g dough pieces

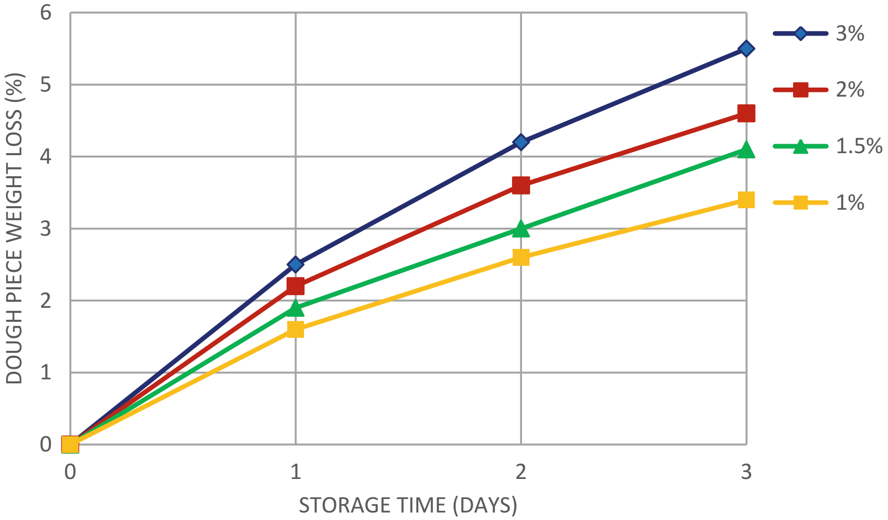


Fig. 6.2 Effect of storage time and yeast level (% flour weight) loss from 60 g dough pieces

and stored for 3 days at 3 °C (38 °F) are compared. For the highest yeast level illustrated, 3 % flour weight, the increase in volume approaches threefold. Such an increase is very similar to that observed under normal proof at much higher temperatures, though with shorter times.

Retarding Temperature

The initial cooling rate of the dough and the temperature at which the storage phase is carried out have a considerable influence on final product quality. The effect of retarding temperature, whatever the equipment used, can be considered in three broad temperature ranges:

- Above the freezing point of water, 0 up to 5 °C (32–41 °F);
- Between 0 and –5 °C (32–23 °F), the latter being the approximate freezing point of bread dough because of the dissolved recipe salt (lower if sugar is also present);
- Below –5 °C (23 °F).

The rate at which dough pieces cool when placed in a retarder depends to a large extent on the temperature within the unit; in general the lower the retarding temperature the faster the cooling rate. An example of how retarding temperature affects the rate of cooling is given in Fig. 6.3, where the effects of four different retarding temperatures on the temperature at the centre of dough pieces for 60 g rolls are compared. The sharp rise in temperature at the centre of the dough pieces cooled at –9 °C (16 °F) coincides approximately with the temperature at which the roll dough pieces froze. The freezing point of the roll dough is somewhat lower than that of a standard UK bread dough because of the presence of sugar in the formulation.

The actual rate at which dough pieces cool is more complicated than the example given in Fig. 6.3. Fermented doughs are poor conductors of heat, and because of this the rate at which the centre cools is much lower than that of the surface. The actual differences in cooling rates between the surface and centre are related in part to the retarding temperature but are mostly influenced by product size, or more specifically product radius; the larger the dough piece radius the greater, the temperature differential for a given retarding temperature over a given period of time.

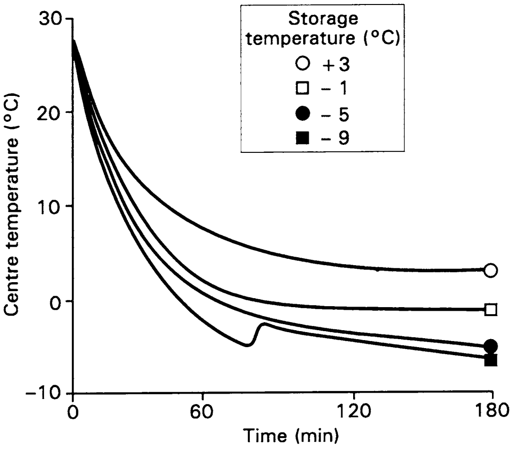


Fig. 6.3 Effect of retarding temperature on changes in 60 g dough piece centre temperature

Yeast activity in the dough continues during the initial cooling and subsequent storage periods as long as the temperature is not so low as to cause the dough to freeze. The activity is more vigorous in the warmer parts of the dough, such as the centre, because of the poor conductivity of the dough. In some circumstances considerable gas production and expansion of the dough can occur. The actual quantity of gas produced depends on the yeast level, initial dough temperature, retarding temperature, the ability of the dough to retain the gas being produced and several other factors. The influence of retarder storage temperature on the expansion of 60 g roll dough pieces with the same yeast level is illustrated in Fig. 6.4. For dough pieces placed for storage in a unit set at −9 °C (16 °F) there is a small degree of expansion which stops once the dough is frozen. At higher storage temperatures the dough can continue to expand so that at 3 °C (38 °F) the dough piece can double in size during retarded storage.

Weight losses from the dough pieces during storage are also significantly influenced by the retarding temperature, with greater weight losses being sustained at higher temperatures (Fig. 6.5). As discussed above, weight losses are linked with skinning of the dough pieces and subsequent quality losses in the final product. When stored at temperatures between 0 and −5 °C (32–23 °F) the surfaces of the dough pieces may be dry to the touch but are less likely to develop a thick skin, unless stored for more than 3 days.

Products made from dough pieces which have skinned frequently exhibit irregular shapes and always have a crust colour with a pale grey cast. In extreme cases, dough pieces may lean towards air inlets because the part of the dough facing the inlet air is subjected to greater moisture loss than the trailing edge of the piece, so that expansion during proof is uneven and is severely restricted by the surface skinning.

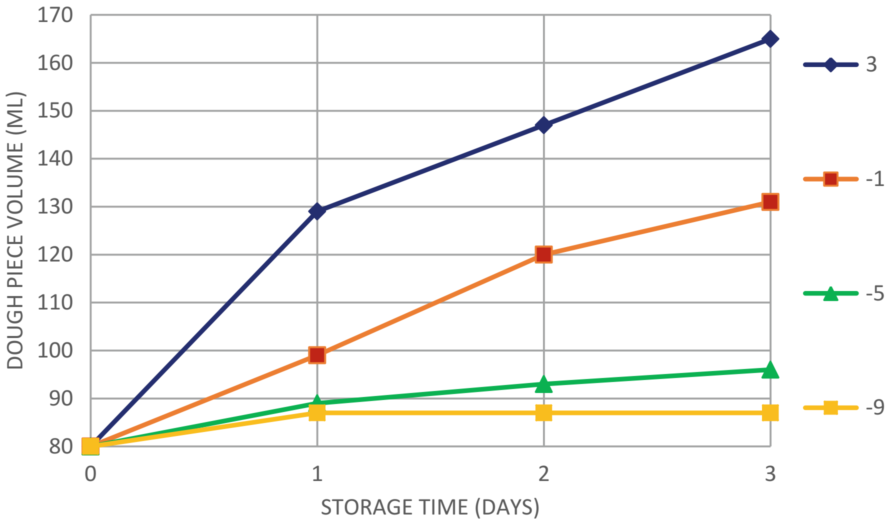


Fig. 6.4 Effect of storage time and temperature (°C) on dough piece volume

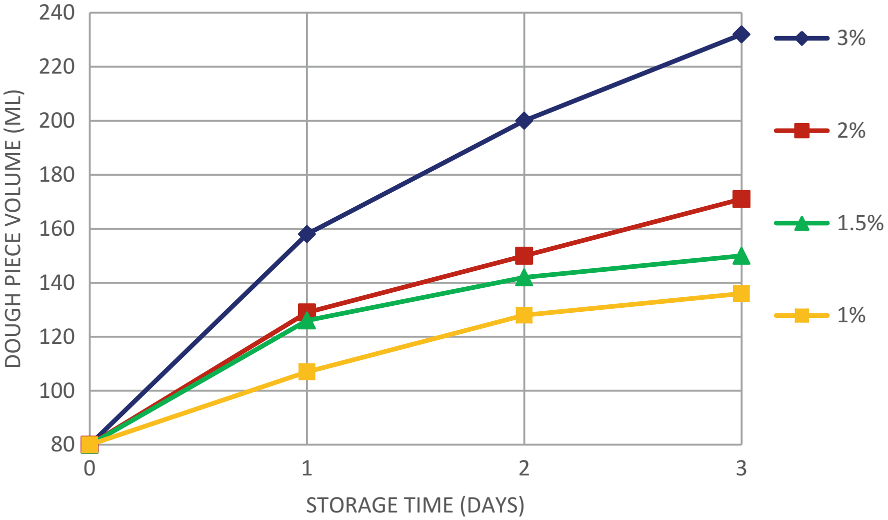


Fig. 6.5 Effect of storage time and yeast level (% flour weight) on dough piece volume

Although many retarder–provers can operate at temperatures below −5 °C they are not usually recommended for freezing dough because of their low freezing rates by comparison with blast freezers. The poor conductivity of dough combined with the low freezing rate achieved in most units allows gas production to continue at the centre of the dough piece for some time after the surface has become frozen. Within the dough piece sufficient expansion can occur to cause the frozen surface to crack. These cracks in the surface do not close during the post-retarding phases and remain on the surface of the baked product. Dough pieces of large radius are more likely to display this problem than smaller ones.

Storage Time

The longer dough pieces are stored under retarded conditions, the poorer the final product quality will be. The nature and magnitude of the decline in quality depends on factors such as dough piece size, yeast level and storage temperature. As a general rule the storage period for retarded doughs seldom exceeds 3 days mainly because of quality losses associated with dehydration of the dough pieces. The volume of dough pieces generally increases as storage time increases. The rate of increase of dough piece volume with time is greater for higher storage temperatures and yeast levels (Figs. 6.4 and 6.5). Despite the increase in dough volume which occurs during storage, there is usually a progressive loss of volume in the baked product, the appearance of surface blemishes becomes more common and the cell structure becomes more open. These defects in product quality can be minimized, and in many cases prevented, by lowering the yeast level, storage temperature, or both, within the limits already discussed.

Weight losses from dough pieces increase with increasing storage time. This progressive weight loss from the dough pieces is mostly related to the loss of moisture. Although there is a contribution to weight loss from any escaping carbon dioxide gas resulting from the slow but continuing yeast fermentation of sugars, either natural or added in the dough, weight losses from this source are small despite the long fermentation times which are involved. Moisture lost from the dough pieces is held in the air in the retarder as the RH reaches equilibrium with the dough. After this point is reached weight losses should cease, but during the operation of the retarder some of the moisture in the air will form as ice on the coils, however efficient the design of the latter. The formation of ice removes moisture from the air and lowers the RH, which becomes lower than the equilibrium relative humidity (ERH) of the dough, and so further moisture losses occur as the system again tries to reach equilibrium. As well as condensation on the coils, some moisture will be lost from the retarder through the opening and closing of the doors and some smaller losses occur through door seals. Some of the moisture losses are offset in retarders which incorporate a defrosting cycle in their normal operation, since the water generated from the melting ice on the coils returns to the air within the retarder.

The rate of moisture loss with increasing storage time is greater at higher storage temperatures as shown in Fig. 6.1, because the saturated vapour pressure (SVP) of the air is lower as its temperature falls. The lower SVP means that a smaller quantity of water is required to achieve saturation of the air. Weight losses with increasing storage time are also greater with higher yeast levels (Fig. 6.2). The progressive loss of weight which occurs in all dough pieces must be taken into account when deciding on the initial scaling weight to be used, especially for products which are subject to weight control at the point of sale.

Enzymic activity in the dough also continues during storage, the rate of the action depending on the storage temperature used. One enzyme to be noted in this context is *alpha*-amylase which may occur naturally in the flour as cereal *alpha*-amylase or may be added by the miller or baker as malt flour or in improvers (Chap. 3). *Alpha*-amylase breaks down the damaged starch to produce soluble carbohydrates and dextrins, some of which caramelize during baking to give the product a darker crust colour which may be undesirable. Other potential enzymic action in the dough during retarding can include the actions of proteinase and protease, the collective actions of which are to weaken the dough structure through interaction with the flour proteins. This may lead to a loss of gas retention and spreading or flow of the dough during retarding which will be accentuated during proof and the early stages of baking. Such enzymic actions will certainly contribute to the progressive quality losses observed with increasing storage times. In order to limit such effects of added enzymes retarding temperatures should be kept as low as possible. Alternatively improver formulations or flour specifications may need to modified to reduce enzymic activity.

Proving and Baking

At the end of the retarding cycle the dough must be proved and expanded ready for transfer to the oven for baking. Even under scratch production the poor conductivity of dough results in a temperature differential between surface and centre by the end of proof. Since retarded doughs are much colder than scratch doughs when they enter the proof phase it is important to raise the temperature of the dough piece gradually and uniformly during the warm phases of the proof cycle. There are two main ways in which this can be achieved; one is to use cool proving temperatures and the other is to modify yeast levels.

Proof to a constant dough piece volume is a time and temperature-dependent operation so that any reduction in proof temperature requires a compensatory increase in proof time, and vice versa. When proving retarded doughs, uniform heating is more critical than overall proof time. This is especially true of retarder–provers, where the change from retarding to heating is automatically controlled and the absolute timing of the switch from one state to another is less critical. The effect of proving temperature on the quality of pan breads from retarded doughs is illustrated in Fig. 6.6. Both dough pieces were proved to constant volume in the pan immediately before entering the oven, thus the pieces proved at 21 °C took longer to reach the required volume. The extra oven spring exhibited by the dough proved at 21 °C (70 °F) results from the more uniform temperature distribution within the piece. Although the dough piece proved at the higher temperature had reached the same volume, it had done so with a larger temperature differential in the dough. In effect, the outer layers of the piece were over-proved and the inner layers under-proved; the former would be over-expanded and exhibit reduced gas retention, and the latter would be too cold to achieve full gas production before the dough became set in the oven.

An alternative way in which to control the uniformity of proof is to prolong the proving time at any given temperature by manipulating the yeast level. This approach has a dual benefit for the quality of the retarded dough in that it will also decrease

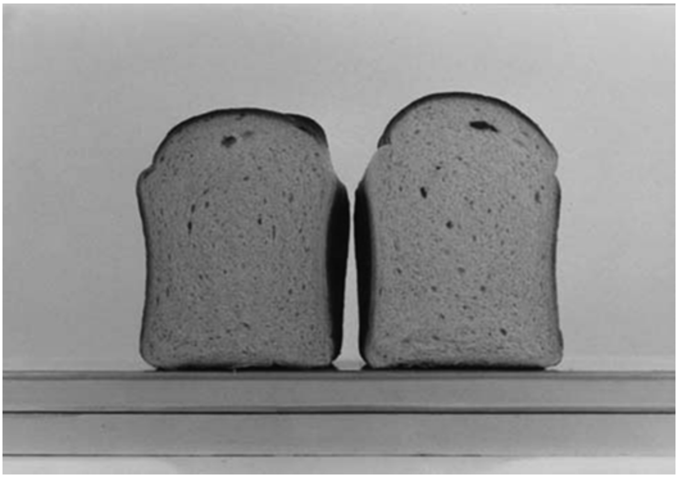


Fig. 6.6 Effect of proving temperature on bread quality, left, 40 and right, 21 °C (70 °F)

Fig. 6.7 Effect of yeast level on bread quality

the likelihood of quality defects such as white spot formation or skinning. An example of the benefits of lower yeast levels is illustrated with pan breads in Fig. 6.7. Once again, all dough pieces were proved to constant volume before they were transferred for baking. Dough pieces with lower yeast level took longer to reach the required volume and the extra oven spring with the lowest yeast level arises directly from the more uniform temperature distribution within the dough achieved because of the longer residence time in the prover. Such results are largely the opposite with scratch doughs. A critical factor in determining the choice of proving conditions will be the initial size of the dough piece. For the same conditions of yeast level and proving temperature, differentials within the piece will be greater for dough pieces of large radius than those of small radius, just as they were in cooling.

In the case of processes where the retarder and the prover are separate pieces of equipment, it is helpful to introduce a 'recovery' stage between the two unit operations to help minimize dough piece temperature differentials. Traditionally recovery is carried out in the bakery to raise dough temperatures to around 16 °C (60 °F), depending on ambient temperature, the dough piece size and other factors. The doughs will need to be covered to prevent moisture losses and skinning.

Adjustment to the baking conditions when using retarded doughs is usually unnecessary; except with higher storage temperatures and longer storage times which may lead to increased enzymic activity and darker crust colours. Undesirably high crust colour can be lessened by lowering slightly the level of ingredients, such as skimmed milk powder, sugars and malt flour, which also contribute to crust colour.

Guidelines for Retarded Dough Production

There are many potential combinations of yeast level, dough piece size, retarding temperature, storage time and proof time which will give acceptable retarded products, and so it is not possible to give precise 'rules' by which they should be produced. It is possible however to give some general guidelines on which to base choices. They include the following:

- Reduce yeast levels as storage times increase;
- Keep yeast levels constant when using separate retarders and provers;
- Reduce yeast levels as the dough radius increases;
- Reduce yeast levels with higher storage temperatures;
- The lower the yeast level used, the longer the proof time will be to a given dough piece volume;
- Yeast levels should not normally be less than 50 % of the level used in scratch production;
- For doughs stored below −5 °C, the yeast level may need to be increased;
- Reduce the storage temperature to reduce expansion of and weight loss from dough pieces;
- Lower the yeast levels to reduce expansion and weight losses at all storage temperatures;
- Dough pieces of large radius are more susceptible to the effects of storage temperature;
- The low freezing rate achieved in most retarder–provers combined with the poor thermal conductivity of dough can cause quality losses;
- Prove dough pieces of large radius at a lower temperature than those of small radius;
- Lower the yeast level in the dough to lengthen the final proof time and to help minimize temperature differentials;
- Maintain a high relative humidity in proof to prevent skinning.

Retarding Pizza Doughs

Some pizza restaurants store ready-made dough bases in a refrigerator or retarder, withdrawing them for topping and baking as required. Proof may be given to the bases either before entering the refrigerator or oven, or both. The composition of pizza bases is not too dissimilar to that of other fermented products and so the effects of yeast level and retarding temperature follow the same pattern. Since the base dough is usually thin, the cooling rate is very rapid, as is the warming rate but the large surface area of the base makes them susceptible to skinning unless precautions are taken to cover the surfaces, for example by stacking pans inside one another.

Novel methods for producing consistent pizza base quality using retarder–provers have been developed based on an automatically controlled cold–warm–cold cycling (Cauvain 1986). The technique makes use of the narrow cross-section of the bases and after shaping and panning-up consists of three storage conditions:

1. An initial retarding period of up to 24 h at –4 °C (25 °F);
2. A proof period of 3–4 h at 21 °C (70 °F);
3. A return to retarding at –4 °C where the bases are held until required and then withdrawn for immediate topping and baking.

It is unusual to retard dough pieces which have undergone proof or significant fermentation before cooling because of potential problems with quality losses, especially the formation of white spots. However, in the case of the thin pizza base the cooling is so rapid that significant quality losses cannot occur. Once in the second retarded condition the bases remain relatively unchanged for up to 8 h.

Freezing Dough

The problems of cooling dough associated with its poor conductivity have already been referred to above in the section on retarding. The low temperatures required to freeze fermented doughs and suspend yeast activity exacerbate those problems associated with poor conductivity, and restrict the choice of breadmaking process which may be used for the manufacture of frozen dough even more than with retarded doughs (Cauvain 2014). However, despite these drawbacks the range of dough sizes which may be frozen and stored is somewhat greater than that usually encountered with retarded doughs.

Breadmaking Process, Recipe and Yeast

The instability of frozen doughs made with significant periods of fermentation before freezing has been shown by a number of workers (Godkin and Cathcart 1949; Merritt 1960; Kline and Sugihara; 1968). Straight or no-time doughmaking processes, such as the Chorleywood Breadmaking Process (CBP), provide the most suitable processes for frozen dough production, as does sponge and dough, provided that the sponge is combined with a no-time doughmaking stage (Cauvain and Young 2001). The recipe for frozen doughs should be based on one which yields acceptable product quality in scratch production, and it is essential that the recipe formulation and the choice of fat and composite improver are compatible with the breadmaking process chosen.

The loss of gassing activity in frozen doughs is well documented (Cauvain 1979; Dubois and Blockcolsky 1986) and is most obviously manifested as an increase in proof time with increasing storage of the frozen dough (Fig. 6.8). The illustrated results not only show the significant difference in proof time between the two yeast levels used but also suggest that the rate at which proof time increased with increasing storage time was lower with 2 % than with 4 % yeast. The loss in gassing activity is mainly due to the loss of viable yeast cells during the initial freezing and during subsequent storage and, as shown in Fig. 6.8, can be compensated for by raising the yeast level in the recipe. In addition to the loss of gassing, there is a progressive loss of product volume with increasing storage as illustrated in Fig. 6.9. Unlike the effect on proof times, the rates at which product volumes decreased with storage time were similar for both 2 and 4 % yeast.

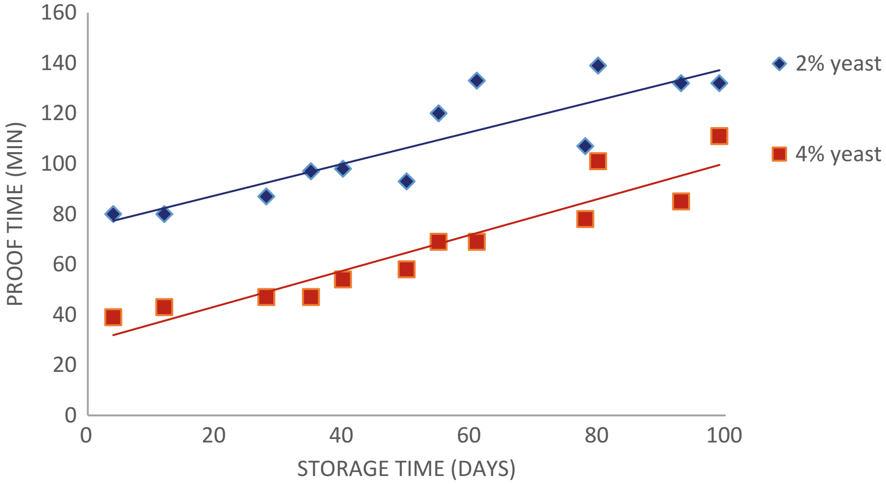


Fig. 6.8 Effect of yeast level (% flour weight) and storage time on proof time

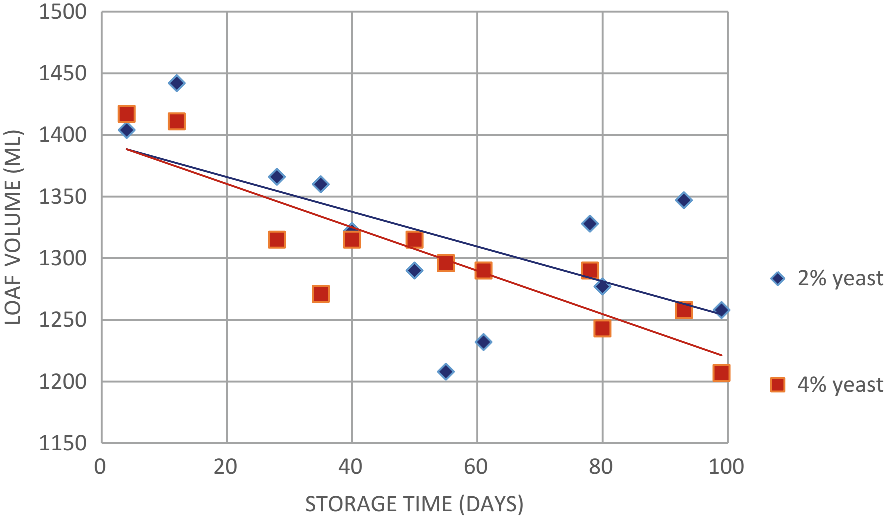


Fig. 6.9 Effect of yeast level (% flour weight) and storage time on loaf volume

Volume losses with frozen dough typically occur even when dough pieces are proved to the same volume before entering the oven. Loss of oven spring accounts for the volume difference and is probably linked with the release of enzymes and reducing agents from the contents of dead and disrupted cells (Hsu et al. 1979). Weakening of frozen dough can occur independently of any detectable loss of yeast activity (Bruinsma and Giesenschlag 1984), although it is not clear just how significant this effect is in comparison with the effect of yeast cell contents.

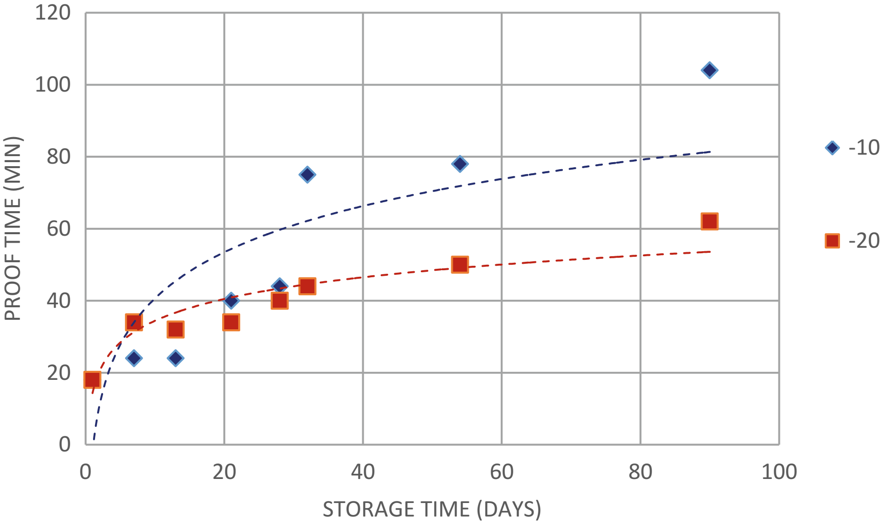


Fig. 6.10 Effect of storage time and temperature (°C) on proof time

The same processes also most certainly account for the appearances of large blisters on some dough pieces during proof, a condition which is commonly associated with the use of weak flours and the lack of gas retention in scratch doughmaking.

Casey and Foy (1995) reviewed the effects of freezing and thawing on yeast cells and the mechanism by which cell damage occurred. In particular they considered the work of Mazur (1970), which showed that the yeast cell membranes lose their ability to block the passage of ice crystals below about −10 to −15 °C (14–5 °F). Usually frozen dough products reach temperatures around −20 °C (−4 °F), if not during initial freezing then certainly during frozen storage. Ice crystals probably continue to grow with increasing storage time and under these conditions we can expect significant damage to cell membranes. The practical evidence reinforces the critical nature of the storage temperature on yeast activity with increases in proof time of thawed dough pieces being less if they have been stored at −10 than at −20 °C (Fig. 6.10).

The compensatory increase in yeast level which is required depends in part on the length of the anticipated frozen storage time. For short periods of storage, say 3–4 days, an increase in yeast level may be unnecessary, while for periods of up to 30 days increases of up to 50 % may be required. For storage periods in excess of 30 days an increase in yeast level of 100 % may be necessary.

The susceptibility of yeast cells to damage, both during the initial freezing and subsequent frozen storage, has led to the development of yeast strains with improved freeze–thaw resistance. Such developments and strategies have been thoroughly reviewed by Casey and Foy (1995). In some cases the newer yeast strains have initially lower gassing rates compared to standard yeast which made them more suitable for the production of frozen dough (Hino et al. 1987; Baguena et al. 1991). Other approaches have included the use of trehalose-enriched yeasts, with the trehalose acting as a cryoprotective agent, and the application of dried yeasts, although successes with the latter have been somewhat variable (Spooner 1990; Neyreneuf and Van der Plaat 1991).

Processing and Freezing Doughs

As discussed above with retarded dough no changes to standard mixing techniques are necessary and changes from the scratch dough norm for dough temperatures should be avoided wherever practicable. Once again, the temptation is to use doughs which are colder than normal in order to reduce gassing activity in the dough before it enters the freezer, but this will have an adverse effect on dough oxidation and enzymic action and the benefits of controlling gassing may well be lost in reduced bread volume and poorer cell structure.

Doughs should be processed as rapidly as possible in order to avoid excessive gas production before freezing, especially if yeast levels which are higher than normal have been used. It may be necessary to mix smaller quantities of dough than normal in order to achieve more rapid processing after mixing. The limiting of intermediate proof between first and second moulding reduces gassing activity before freezing and slightly reduces the vulnerability of yeast cells. The resulting bread has a slightly finer cell structure and is less prone to the formation of small white spots on the surface of the product. These effects are related to improvements in gas retention in the dough, with shorter final proof times to constant height (Fig. 6.11) and better loaf volume with increasing storage time (Fig. 6.12).

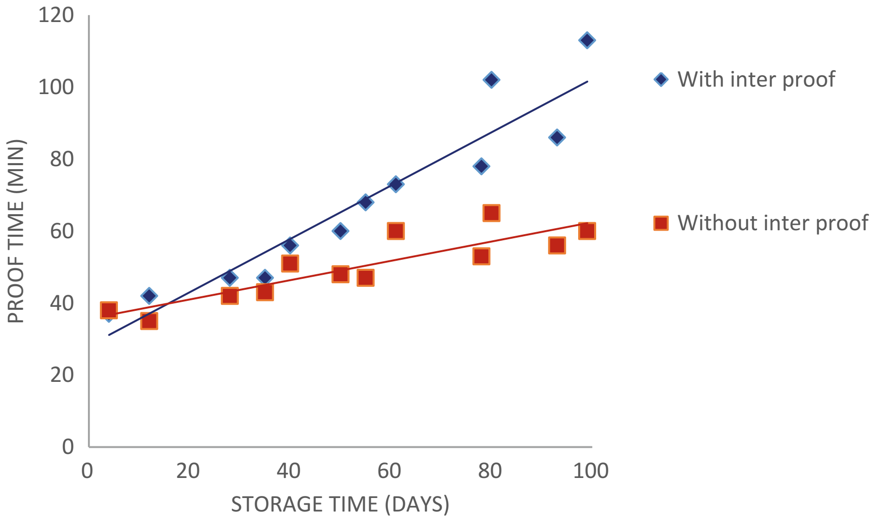


Fig. 6.11 Effect of intermediate proof and storage time on proof

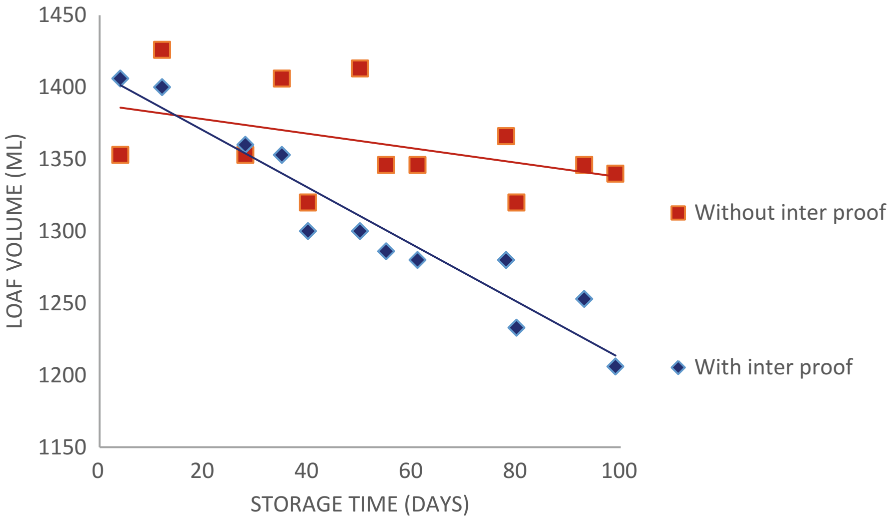


Fig. 6.12 Effect of intermediate proof and storage time on loaf volume

A simple but often overlooked effect of the freezing process is that it fixes the dimensions of a dough piece, and it may be necessary for some adjustment to be made to the moulder in order to ensure that the frozen pieces will fit in pans, or on trays, at the point of end use before defrosting. Dough pieces should be transferred to the freezing unit as quickly as possible after final moulding to reduce gassing activity and yeast vulnerability.

The freezing operation is best carried out as rapidly as possible to inhibit yeast activity though some sources consider that slow freezing is better. Part of the problem with understanding what is the optimum freezing rate lies with the rather loose definitions of fast and slow freezing (Le-Bail and Gabric 2012). It is probably easier to consider the concept of freezing rate by considering the types freezer that might be used in the manufacture of frozen dough. Of the types of freezer available, the blast freezer offers the best compromise between speed and operating temperatures. It is recommended that no part of the dough is subjected to temperatures lower than −35 °C (−30 °F) to avoid excessive damage to the yeast cells present in the dough. Domestic-type freezers are generally not suitable for producing large quantities of frozen dough because the very low freezing rate (defined as the change of temperature within a dough piece in unit time, typically less than −0.21 °C/min in a domestic chest freezer) allows too much gas production to occur in the early stages of cooling with a subsequent loss of product quality. The low freezing rate that is achieved in most retarder–provers also largely makes then unsuitable for producing deep-frozen dough pieces, except for those products with a small radius, such as rolls. In a typical blast freezer variations in air velocity have little effect on dough performance and bread quality (Cauvain 1979).

The changes which occur in fermented doughs during freezing are mostly related to the size of the dough piece and the temperature at which freezing takes place. Dough pieces with large radii take longer to reach a given temperature at the centre than those with small radii. Figure 6.13 illustrates changes in the temperature at the centre of a dough piece for a typical range of bakery dough pieces during freezing. Plotting the freezing rates for these dough pieces against dough radius (Fig. 6.14) confirms the close relationship between the two parameters. Further confirmation of the critical role of dough piece radius is given in Table 6.1, where the freezing rates of dough pieces each weighing 910 g (2 lb) but having different configurations are compared.

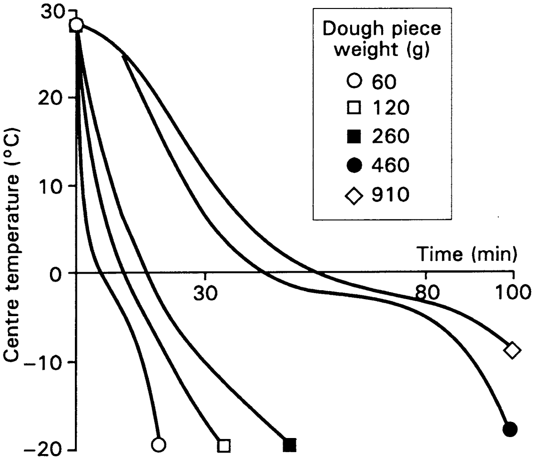


Fig. 6.13 Changes of centre temperature with freezing time

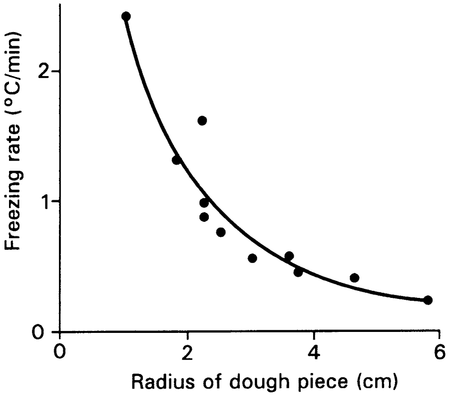


Fig. 6.14 Effect of dough piece radius on freezing rate

Table 6.1 Effect of radius on dough freezing rate

Nominal shape	Length (cm)	Radius (cm)	Volume (cm^3)	Freezing rate (°C/min)
Cylinder	22.0	3.75	884	0.46
Cylinder	55.0	2.50	1080	0.75
Sphere	–	5.75	797	0.24

In addition to affecting freezing rate, the radius of the dough piece will also affect the temperature differential which will be set up between the surface and centre. As discussed above with retarded doughs, pieces with large radii will cool with a larger temperature differential than those with small radii. An example of the changes which can occur during the freezing of a 460 g (1 lb) cylindrical dough piece are illustrated in Fig. 6.15. In this example the centre temperature has taken nearly twice as long as the surface temperature to reach the frozen state, around −5 °C (23 °F), as shown by the inflexion on the centre temperature curve in Fig. 6.3 after 80 min. In dough pieces with large radii the temperature at the centre remains relatively high for long periods of time, which allows considerable gas production to occur. The dough piece can, depending on yeast level, expand by up to 50 % of its original volume. Typical times taken for a standard dough piece to reach three given centre temperatures in a blast freezer are given in Table 6.2 together with the calculated freezing rates.

Frozen products need to be held in storage below their glass transition temperatures in order to prevent change and deterioration during the storage period. Glass transition temperatures are formulation sensitive and so, in theory at least, every product will have its own unique minimum storage temperature. In commercial practice a storage temperature of about −20 °C (−4 °F) is usually applied, which is well below the glass transition temperature of fermented dough formulations. There is always a temptation for dough pieces to be transferred to frozen storage

Fig. 6.15 Effect of freezing time on dough temperature

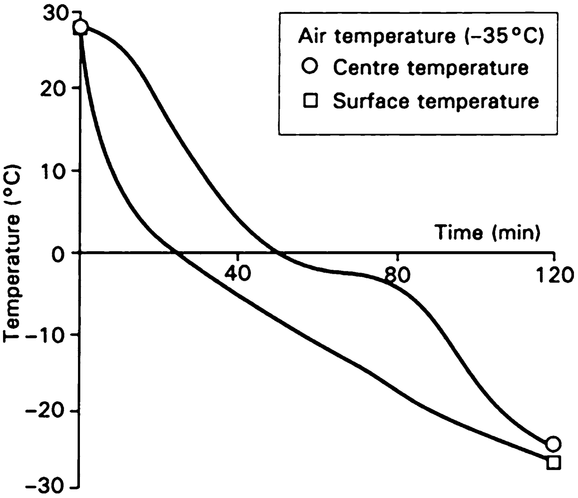


Table 6.2 Freezing times and rates

Centre temperature achieved (°C)	Time taken to cool from 30 °C (min)	Average freezing rate (°C/min)
0	47	0.62
−10	86	0.44
−20	110	0.44

Table 6.3 Equalization times

Centre temperature (°C)	Time taken (h) for centre to reach storage temperature	
	−10 °C	−20 °C
0	5	11
−10	0	1.5
−20	1.75	0

once the surface is frozen but, as the curves given in Fig. 6.15 show, the central dough temperatures will higher at any given time during the initial freezing. In the storage period which immediately follows blast freezing, the dough pieces typically undergo a further cooling period. The length of that period depends in part on the particular storage temperature being used as shown from examples given in Table 6.3.

Changes in frozen dough performance occur with increasing storage time, the most obvious of which are lengthening of proof time (Fig. 6.8) and a progressive loss of product volume (Fig. 6.9). Even when stored at −20 °C (−4 °F), frozen dough pieces are able to lose water and thus for storage should be wrapped in polyethylene bags or boxes over-wrapped with polyethylene before transfer to the storage freezer.

Defrosting and Proving

Because dough is a poor conductor of heat, the patterns of temperature change that occur in dough during defrosting are similar, in reverse, to those which occur during freezing, and a series of examples are compared in Fig. 6.16. As with the freezing process there will be a temperature differential between the surface and centre of the dough piece during defrosting. In Fig. 6.17 the temperature profile of a defrosted dough piece is compared with that typically observed in a scratch dough during proof. The curves show clearly the large temperature differential which exists between the surface and the centre of the defrosted dough. While the surface temperature after 50 min proof at 43 °C (110 °F) was only slightly lower than that of the scratch dough, the centre temperature was 25 °C (45 °F) lower. At the end of proof both dough pieces had the same volumes in the pan, but the bread baked from the frozen dough was the smaller of the two with a ragged crust break and a much denser crumb structure at the centre of the loaf (i.e. typical of an underproved dough piece or products made with cold dough).

Temperature differentials such as the one illustrated in Fig. 6.17 can be minimized by gradual defrosting at more modest temperatures and under controlled conditions similar to those discussed in the section on retarding. Indeed retarder–provers offer a suitable means by which to raise gradually the temperature of the dough pieces and to minimize the temperature differential within them. However, standard retarders are designed only to cool dough and will be inadequate for defrosting when completely filled with frozen dough unless they incorporate provision for heating.

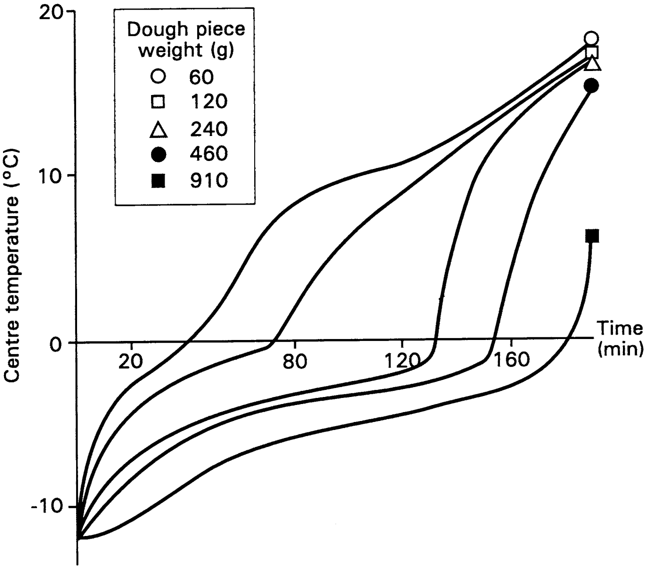
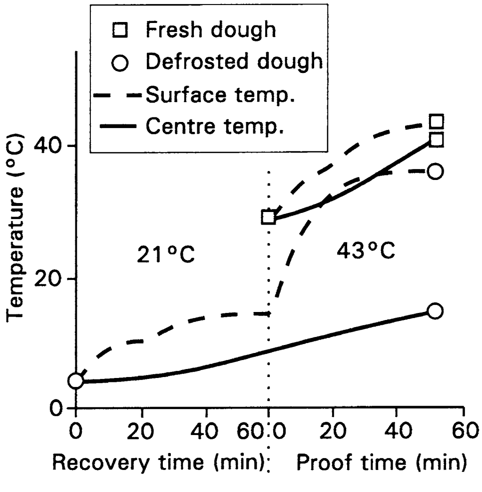


Fig. 6.16 Changes of dough piece centre temperature with defrosting time at 21 °C (70 °F)

Fig. 6.17 Changes in dough temperature during recovery and proof



Freezing Proved Doughs

It is possible to freeze doughs which have undergone a period of proof but these products will behave quite differently from unproved frozen dough during freezing, storage and baking. In proved dough pieces the yeast will have been fully activated and is more susceptible to damage from temperature shock. Large numbers of yeast cells will die during the initial freezing and more will die during the frozen storage period. It is likely that in a short time, probably only a few days, that there will be no viable yeast cells left in the dough. In such circumstances the dough will have a reduced ability to expand during the early stages of subsequent baking because no ‘extra’ carbon dioxide gas will be generated from yeast fermentation, such as would be seen in scratch or other frozen doughs. Any expansion of the dough during baking will come from the thermal expansion of gases trapped in the dough, supplemented by water vapour expansion.

In all proved dough pieces the gas mixture comprises a mixture of nitrogen bubbles which provide the nuclei for carbon dioxide generated by the yeast. Any oxygen originally incorporated into the dough will have been rapidly used by the yeast during or immediately after mixing. The potential expansion of the dough during proof and the early stages of baking thus depends on these gases being retained within the dough matrix. At the warm temperatures experienced during proof, carbon dioxide is constantly being generated by yeast fermentation, going into solution and diffusing into the trapped nitrogen gas bubbles. When the dough is cooled, the diffusion process is reversed because of the high solubility of carbon dioxide at low temperatures compared with that of nitrogen (Sluimer 1981). Without the inflating effect of the carbon dioxide gas the nitrogen bubbles shrink in size; some may become so small that they cease to exist and the nitrogen gas from them diffuses out of the dough system into the atmosphere. In frozen proved doughs this diffusion process manifests itself as a collapse of the dough structure. During storage this collapse or shrinking continues (LeBail and Gabric 2012), and with no yeast activity available at bake-off there is insufficient compensatory increase in gas expansion. In addition, the nitrogen bubbles which remain in the dough are those which had an initial larger bubble size, and the resulting bread is very open in cell structure.

Amongst the more successful of frozen proved products are those which contain yeast and which are laminated, e.g. croissant and Danish. In such products the final quality depends more on the ability of water vapour to force apart the dough layers during baking than on the generation of carbon dioxide from yeast. The vapour-resistant properties of the dough layers depend to a large extent on the integrity of the dough layers and the physical properties of the fat (Cauvain 1995; Cauvain 2001). When frozen proved laminated products are transferred to the oven they still have the potential to expand and yield products of relatively ‘normal’ appearance.

Factors Affecting the Formation of White Spots on Retarded and Frozen Doughs

Perhaps the most common of the quality losses associated with retarded and frozen doughs are the very small, translucent blisters or ‘white spots’ which sometimes occur on the top and bottom crusts of the baked product. They are not usually seen on the surface of the dough piece at any of the stages before baking, but very quickly become visible as the crust begins to colour. Observations of cross-sections of suitable dough surfaces under a light microscope confirm their presence before baking.

The mechanism by which these white spots are formed still remains to be fully elucidated, but it is clear from research that any change which affects the production of carbon dioxide gas during the retarding or defrosting phases will influence their formation. The occurrence of white spots is associated with significant gas production before or during retarding. They are more likely to occur with high yeast levels, high storage temperatures, long storage times and even very slow defrosting in the case of frozen doughs. This evidence suggests that the significant factor in their formation is the high solubility of carbon dioxide gas at low temperatures as discussed above.

It is interesting to note that dough pieces which skin during the retarding phase do not normally exhibit white spots, which implies that high moisture content at the surface of the dough favours their formation. Some additional evidence for this view is provided when the bases of some retarded products, such as rolls, are examined. They show a similar formation of white spots, although their drier upper surface may exhibit skinning. The base surface of the dough is protected from the drying effects of the retarder atmosphere or air movement because of its intimate contact with the metal sheet or paper surface on which it stands. Pan bread can exhibit white spot formation on the upper crust and also a similar phenomenon on the side crusts. In the latter case the white spots appear to combine and form into patches having a ‘waxy’ appearance, which are sometimes referred to as ‘condensation spotting’ (Sluimer 1978). Once again, the white spots seem to form most readily where the dough surface is protected from moisture loss, in this case by the sides of the pan.

This apparent relationship between white spot formation and higher moisture content may also help us to understand why the spots are translucent and contrast so readily with the darker crust areas. Under the microscope there is some evidence of water droplets suspended within the voids, which become white spots. This ‘extra’ water may act as a diluent for the colour-forming components within the dough, quite literally reducing the local concentration of sugars. The white cast that is observed when dough pieces skin occurs for quite different reasons. Here it is likely that the loss of moisture significantly reduces the Maillard browning reactions which normally occur.

It has been observed that the appearance of white spots is also related to the gas-retaining ability of the dough. White spots may occur when the dough has poor gas retention, and white spots are more likely to occur even when the retarding temperature and yeast level have been optimized. Because such a wide range of factors affect their formation it is difficult to predict their appearance with certainty.

Reductions in recipe yeast levels together with lower retarding temperatures are often the most effective means of eliminating or reducing the incidence of white spots. Other changes which may be beneficial include reducing periods of bulk fermentation after mixing and minimizing delays after final moulding before transfer to the retarder or freezer. Traditional remedies for eliminating white spots have been to increase the degree of dough ‘enrichment’, usually sugar, fat or both or through the addition of emulsifiers. Sugar slows down (retards) yeast activity while increasing fat levels or adding an emulsifier contribute to improved gas retention in the dough (see Chap. 3).

Not all process changes affecting the formation of white spots occur during the retarding phase. There is evidence that white spots are more likely to occur if the rate of warming of dough pieces after retarding is particularly low as a result of using a very cool proof temperature (e.g. 12 °C, 54 °F) or very low yeast levels (e.g. 1 % of flour weight) or both. Supporting evidence was seen in work on frozen dough where a study of the defrosting technique needed for frozen lean bread doughs showed that relatively rapid defrosting at 21 °C (70 °F) did not give white spots while slow defrosting via a retarder at 3 °C (38 °F) did (Cauvain 1983).

Causes of Quality Losses with Retarded and Frozen Doughs

Variations in the quality of products made from retarded and frozen doughs may occur from time to time. There are many causes of such quality losses. Some arise from factors which have their origins in the dough formulation and processing conditions which are used before the doughs enter the retarder or deep freeze, while others arise directly from conditions within the refrigeration equipment or as the result of thawing and proving conditions. Identifying the causes of quality losses requires careful consideration of the whole process. A few possible causes of quality losses are given below, but the list is by no means exhaustive.

Skinning

Low humidity or excessive air movement, even with sufficient humidity, may cause the surface of the dough piece to dry out or 'skin' during retarding or recovery (Cauvain 1992). The upper crust will be hard and dry eating. If skinning occurs during retarding there will be a distinct tendency for the dough pieces to lean towards the air inlet. Skinning becomes more pronounced as the storage time increases. It is an irreversible phenomenon and will carry through to the baked products, which may be small in volume and have a 'pinched' appearance as the result of uneven expansion of the dough pieces during baking. Lowering the retarding temperature or the yeast level in the recipe, or both, reduce skinning.

Crust Fissures

Products may sometimes exhibit small fissures or cracks, mainly on the upper crust. The depth of cracking may become significant on occasions. The cracks may be observed on the surface of the dough, and once formed will persist through to the baked product. Slow freezing, such as that encountered in retarder–provers, or excessively high yeast levels are the main causes. Such cracks are more prevalent with dough pieces of large radius. They can be minimized by lowering the yeast level used in the recipe.

Ragged Crust Breaks

These occur most often when there is a large temperature differential between the centre of the dough piece and its surface. It can be a particular problem with frozen doughs of larger size where the poor conductivity of dough exaggerates the temperature differentials. When the dough piece enters the oven the full gassing potential of the dough centre is not realized until after the crust has set and the crust breaks at its weakest points. Generally this will be in the normal crust break area, although it may occur in other places. The only remedy is to give a longer proof using lower temperatures or lower yeast levels, or both.

Small Volume

There is seldom a single cause of small-volume products and usually the problem is linked with other quality losses, such as skinning or ragged crust breaks. Improvements in volume may be achieved by reducing the length of time in storage (both retarded and frozen), optimizing yeast levels, and optimizing retarding and proof temperatures. In the case of frozen doughs, volume losses occur through the loss of activity and the release of proteolytic enzymes and glutathione from disrupted yeast cells.

White Spots or Small Blisters

The origins of the white spots or small blisters on products baked from retarded or frozen doughs have been discussed above. In summary they have their origins in almost any change which affects gas production or retention (Cauvain and Young 2001). They can be eliminated or reduced by lowering yeast levels in the retarded dough recipe, adding fat or emulsifier (Moonen and Bas 2004) where it will not adversely affect other product qualities, reducing bulk fermentation (floor-time) after mixing, and reducing delays before retarding and freezing. Lowering the retarding temperature or the yeast level in the recipe, or both, will eliminate white spots on the top crust and, to a lesser extent, the bottom. Solving a white spot problem in frozen doughs by adjustment of the yeast level is more difficult because of the need to maintain gassing activity in the dough after defrosting. Minimizing gassing of doughs before freezing is a better option, although using lower dough temperatures to achieve this may result in other problems.

Waxy Patches

Patches of uneven colour may occur on the side and bottom crusts of breads baked in pans. They have a shiny or 'waxy' appearance and are frequently observed on the lower corners of the loaves. This phenomenon is sometimes referred to as 'condensation spotting' and its incidence increases as storage time increases, even when the retarding temperature and yeast level have been optimized. The only remedy to this problem is to avoid storing dough pieces in pans at refrigerated temperatures for more than 36 h.

Black Spots

An unusual problem sometimes seen on the bottom of baked products is the occurrence of black spots, often mistaken for mould formation (Cauvain and Young 2001). This phenomenon arises from a reaction between the moist dough and steel baking sheets and can even occur through silicone paper. It is easily overcome by switching to anodized aluminium trays or ones covered in non-stick material. The use of trays with damaged coatings should be avoided.

Large Blisters

Large blisters sometimes occur on retarded fermented products and may often associated with skinning, though this is not the main reasin for the problem. The large blisters are of two sorts: either they protrude from the surface causing a distortion of shape or they appear as a large cavity under the top crust which only becomes apparent when the product is cut. The most common causes are poor moulding and damage to the dough piece during processing which may cause large gas bubbles trapped within the dough piece to become greatly expanded by the carbon dioxide gas released during the proof phase. Poor gas retention will also contribute to this problem, and it will be exacerbated by a short final proof, either as a consequence of using too high a yeast level or too high a proof temperature. Delays in transferring dough from the blast freezer to deep-freezer storage can lead to partial defrosting. Upon subsequent baking large blisters may be present under the top crust.

Dark Crust Colour

Enzymic action can continue in retarded doughs, and to a lesser extent with frozen doughs. *Alpha*-amylase activity is the main activity of concern under this heading as it can produce an increase in available maltose and dextrins, which can contribute to excessive darkening of product crust on baking. Excessively dark crust colours can be avoided by lowering the retarding temperature to reduce enzymic activity, or by reducing the level of added sugars, skimmed milk powder, malt flour or added *alpha*-amylases via the improver.

Uneven or Open Cell Structure

Sometimes doughs which normally produce a fine cell structure yield a more open one when retarded or frozen. More often than not, the origins lie in excessive gas production before the dough is chilled or frozen, or in the early stages of the retarding and freezing processes. The poor conductivity of dough, exacerbated with larger dough pieces can make a significant contribution to the problem. There are a number of possible remedies which include lowering the retarding temperature and reducing delays before retarding or freezing. Controlling cell structure by manipulating the yeast level in retarded doughs presents some problems. To maintain a fine cell structure in retarded products it is necessary to lower the yeast level in order to minimize gas production during the retarding phase. However, lowering the yeast level requires a compensatory increase in proof time in order to maintain product volume, and excessively long proof times can also lead to more open cell structures. With frozen doughs the problem is potentially greater as yeast levels which are higher than normal may be used in order to avoid long proof times. In this case the best option is to keep the processing time between mixer and freezer as short as possible.

Areas of Dense Crumb

This phenomenon may often be associated with ragged crust breaks. Uneven expansion of the dough piece during proof and the early stages of baking is the main cause, such as might be experienced by transferring cold doughs to a hot prover. There is a tendency for this phenomenon to manifest itself more readily as the storage time of frozen doughs increases.

Principles of Refrigeration

In order to cool a product we must have some means of extracting heat from it. For a solid to become a liquid or for a liquid to change to a vapour, it must absorb a large quantity of heat. The heat involved in the transition processes is referred to as ‘latent heat’. If we can find some means of using doughs to provide the necessary heat, we have the basis of a rudimentary refrigeration system. Large quantities of heat are also involved when a vapour changes back into a liquid and then into a solid, but in this case the heat is given out by the material instead of being absorbed.

The transition from liquid to vapour and vice versa forms an essential part of the refrigeration cycle which is used in retarding and deep freezing. In its simplest terms, a refrigeration system has an evaporator coil sited inside a cabinet and a compressor and condenser coil sited outside. All three components are connected and a pump circulates a liquid refrigerant between them. The refrigeration cycle is founded on four basic steps:

1. A reduction in atmospheric pressure on a liquid reduces its boiling point and increases its vaporization rate;
2. The change from liquid to vapour requires latent heat of vaporization;
3. Increasing the pressure of a vapour increases its rate of condensation and the temperature at which it changes to a liquid;
4. Latent heat of vaporization is given out in the change from vapour to liquid.

In our simple refrigeration system, liquid refrigerant is metered into an evaporator where it is vaporized under reduced pressure (step 1). The liquid cools as latent heat of vaporization is absorbed (step 2) and in turn cools the coils through which it is being pumped. The cooling coils have fins attached which considerably increase the potential cooling area of the coil and since the coil is located within a chamber (e.g. retarder), the surrounding air is cooled and in turn any dough pieces contained within the cabinet. The efficiency of the air in cooling the product is improved by circulating the air by means of a fan. The vapour thus created in the evaporator coil passes to a compressor where the pressure is increased (step 3) and the latent heat is given up (step 4) to the atmosphere. Fins are also used in this part of the cycle to increase the efficiency of the condenser coil and rapidly pass the heat to the atmosphere.

Modern refrigeration equipment still uses the basic principles described above, but there have been many improvements in design and operating efficiency. There has been considerable change in the nature of the refrigerants which are used together with improvements in knowledge about their operating efficiency and impact on the environment. In designing a suitable retarder or deep freeze the refrigeration engineer uses information on equipment loading, the specific heat capacity of the products and the materials used in the cabinet or room construction, and other less precise information on ambient operating conditions and the rate at which products will typically give up their heat. However, refrigeration is not a precise science, and while there have been many improvements in equipment design, the behavior of fermented dough products during cooling still remains difficult to model accurately.

Retarder–Provers and Retarders

Retarder-prover design varies but most incorporate the same basic elements. They can be programmed to follow a preset sequence of operations at given times. Initially the equipment is set in the retarding (cold) phase and remains so until, at a pre-set time, it changes to the heating sequence. The unit continues in the proving (warm) phase until it is switched back automatically to retarding. This cycle of events can be programmed in advance for 7 days or longer.

In the retarding phase, warm air drawn from the cabinet passes over the refrigerating coils and is cooled. In smaller models a perforated metal screen in the cabinet ensures that the cool air is distributed evenly over the warm dough pieces. The air is re-circulated over the refrigerating coils and the cooling process continues until the temperature of the air and the dough pieces reaches that set on the thermostat.

The surface area of the refrigerating coils is made as large as possible to ensure rapid cooling and to help in maintaining a high relative humidity in the cabinet during the retarding phase. Initially the air in the cabinet is relatively dry, but the dough pieces gradually lose moisture and the relative humidity of the air increases. As the temperature of the surface of the refrigerating coils is close to, or below, 0 °C (32 °F), some of the water present in the air forms as ice on the coils and the relative humidity of the air falls. In order to maintain relative humidity at equilibrium, the products then lose more moisture.

As the operating temperature of a retarder–prover is reduced, the saturated vapour pressure of the air becomes lower and, therefore, a smaller mass of water is required to achieve a given relative humidity. This lower moisture requirement for the air results in a smaller weight loss from the dough pieces. However, operating at temperatures below 0 °C increases ice formation on the coils and at other locations in the retarder–prover, with the result that the efficiency of the evaporating coils is impaired. Provided that the efficiency of the evaporator coil in keeping the cabinet at the desired temperature is not too badly affected, ice formation is of no great consequence. Indeed, when the retarder–prover changes to recovery and proof conditions, the melting ice can provide some of the water vapour necessary for proving conditions. In such cases the equipment must provide sufficient energy to overcome the latent heat of fusion of ice, as well as for warming the products.

Many retarder–provers include an independent defrosting cycle to keep the coils free from ice, and the water vapour produced helps to reduce the moisture lost from the dough pieces. However, it is important that the temperature rise within the cabinet during this defrosting period is limited; otherwise this will impair product quality.

At the end of the predetermined storage time the operation of the cooling coils ceases and the heating cycle commences. In general, retarder–provers are equipped with several different warming steps, the aim of which is to raise gradually the temperature of the unit and the dough pieces and to hold the latter until they are ready for baking. Humidity will be controlled during the proving phase to prevent skinning of the dough pieces.

In construction, retarders follow much the same lines as those described above with retarder–provers, except that they do not have proving facilities fitted. Retarders more commonly operate within the temperature range 2–4 °C (36–39 °F) and should be able to maintain a relative humidity of about 85 % but some are capable of operating at temperatures as low as −5 °C (23 °F).

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Chapter 7
Process Control and Software Applications in Baking

Introduction

Process control is required in the manufacture of all foods in order to ensure that wholesome, safe and nutritious food is delivered to the consumer. In addition there is a need to deliver the requisite quality consistently so that consumers return to sample products again and again. There are a myriad of process control options which may be used, each of which has its own advantages and disadvantages (Leach 2012). The general principles of process and quality control systems which are intended to deliver 'safe food' can be obtained elsewhere (Wallace 2012). This chapter addresses process control systems and their application to baking from the points of view of ensuring that the technology employed in the bakery is first of all delivering the appropriate dough and bread qualities which are required and secondly that these objectives are achieved in an efficient and cost effective manner. The key difference in using process control as a means of delivering consistent and appropriate product qualities is that the applications have to be able to identify and cope with the variability that arises from the complex ingredient-recipe-process interactions which are at the heart of the baking process. Traditionally once a technical quality defect had been identified it fell within the province of the expert bakery technologist and production manager to deal with based on their experience and expertise (Cauvain 2000). In dealing with quality issues individuals would commonly refer to a set of empirical rules which have evolved from traditional bakery practices over many years. Some elements of objective process and product characteristics may be included as part of the data used for the analysis and identification of likely causes and provision of possible solutions.

With the increasing industrialization of baking and the growth in the size and complexity of bakery operations two important changes occurred. The first was the loss of intimacy between bakers and the dough. Now the subjective evaluation of dough rheology became more difficult to perform since access to the dough at different processing stages was limited and the opportunities to influence dough processing in real time became less possible. For example, many mixing operations

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were carried out in a sealed environment under a pre-set series of conditions until mixing was completed. It was only at the end of the mix cycle that operators could touch the dough and assess its suitability for subsequent processing. This situation contrasts with more traditional open-access mixing environments where operators could take portions of the partly mixed dough and decide whether it needed the addition of more water or extended mixing time.

The second limitation for knowledge application was the increasing use of improvers to supply a range of functional ingredients. In some ways this approach was intended to deliver more consistent dough performance and final product quality. However, the complex nature of the ingredient functions increasingly became the province of ‘scientists’ rather than practical bakers and there was a shift in the knowledge base from bakers to their suppliers. This shift was undoubtedly unintentional when it began but has become unfortunate as the complexity of bakery operations has increased because it has become increasingly difficult for all involved in baking technology to identify and quantify the interactions which contribute most to determining final product quality in modern bakeries.

In the current bakery environment we now have plant which is capable of operating with greater precision and we are able to measure, capture and potentially analyse data in larger quantities than before. We also have a deeper understanding of the chemistry of wheat and flour, and the chemical and physical processes associated with breadmaking. Yet the irony of breadmaking is that we still rely heavily on heuristics and rules of thumb to find solutions to quality problems rather than data analysis. This situation is in contrast with many other manufacturing industries.

It is not the intention of this chapter to debate the reasons for the position that the baking industry finds itself in; rather it is to consider the possibilities for process control, software options and applications related to the technology of breadmaking. If readers wish to gain information on management and financial systems and software options suitable for bakeries they should seek direct guidance from the suppliers of such packages.

Relevant Process Data

In some ways one can argue that all process information is relevant and that it is therefore important to collect as much hard data as possible. In the context of the concerns of this chapter we are seeking to gather objective data on such matters as the recipe, dough quality, processing conditions and final product qualities as possible. With the recent advances in the areas of image analysis, and data capture, storage and analysis it has become increasingly possible to capture relevant data on-line and in real-time. However, it is probably (and disappointingly) true to say that much of the data capture in bakeries takes place off-line and divorced from the production time-line. In part this is because we have yet to fully develop on-line measurement capabilities and in part because working bakeries tend to be seen as a ‘hostile’ environment for computers and relatively delicate measuring equipment. As the mechanization of bakeries increases, the latter argument continues to weaken.

Perhaps more convincing for the lack of automated process control in commercial bakeries is that our ‘process model’ has yet to be well defined to allow the degree of control enjoyed by industries like the manufacture of cars. However, the counter-argument that until we gather the data and attempt to model it then we will never improve our process control is a valid one.

Recipe Data

All bakeries work to some form of standard recipe for a given product so we at least have a relevant starting point. Deviations from standard levels of addition should be, and often are recorded at the mixing stage. Typically in breadmaking variations in recipe water level and to a lesser extent yeast level will be recorded on a regular basis; the former in response to variations in the water absorption capacity of the incoming flour. However, adjustments to water level are rarely assessed or predicted by any form of objective dough rheology testing with the assessment relying on a subjective assessment if possible by bakery personnel. Yeast levels may be adjusted to compensate for variations in ambient bakery conditions; for example; more yeast may be used in colder winter months and less yeast in warmer summer months.

Process Data

Mixing

Since mixing is carried out with a defined set of conditions, to a fixed time or energy, only variations from the standard are commonly recorded in bread bakeries. However, in some types of mixing operations (e.g. CBP-compatible mixers) the energy consumption curve is commonly recorded. Seldom is analysis of the form of the curve or the data which it contains undertaken. Yet such curves are a direct measure of the changes in dough rheology which occur in real time in the dough mixed in a commercial content. The simplicity of CBP-compatible mixer curves with those obtained with common dough rheology equipment (e.g. the Perten Dough Lab) can be striking (Cauvain 2013) with phases related to such accepted dough properties as hydration, peak time/value and breakdown.

If the conditions in the mixer chamber are deliberately varied, e.g. atmospheric conditions adjusted as practiced in the CBP, then changes in dough rheology can be identified. For example, the mixer trace illustrated in Fig. 7.1 shows the effect of reduced pressure in the mixer chamber towards the end of the mixing cycle. One advantage of capturing mixing data in the bakery is that the data record the true commercial situation. Cauvain (2013) illustrated how DoughLab traces changed when mixer speeds were increased to be more compatible with industrial practice and the impact of moving from a water-flour mix to a full commercial recipe (Figs. 7.2 and 7.3). It is possible with mixer energy traces to see the impact of ingredient and recipe changes in commercial practice.

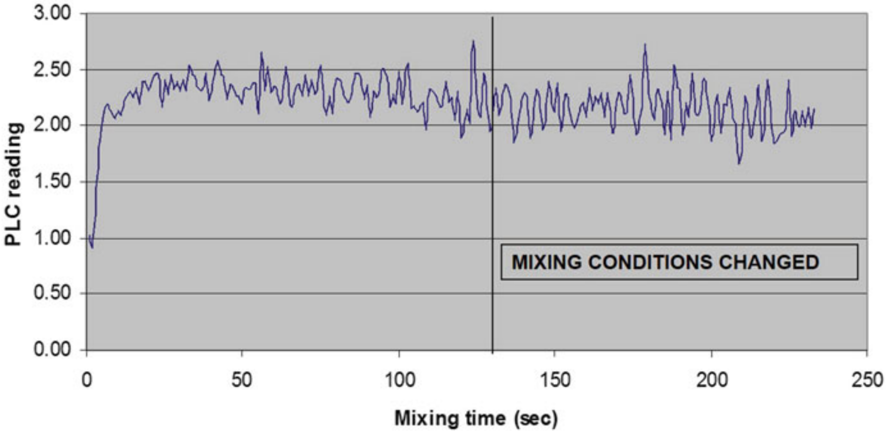

Fig. 7.1 Example of a CBP-compatible mixer energy trace with a processing change partway through the mixing cycle (Courtesy *BakeTran*)

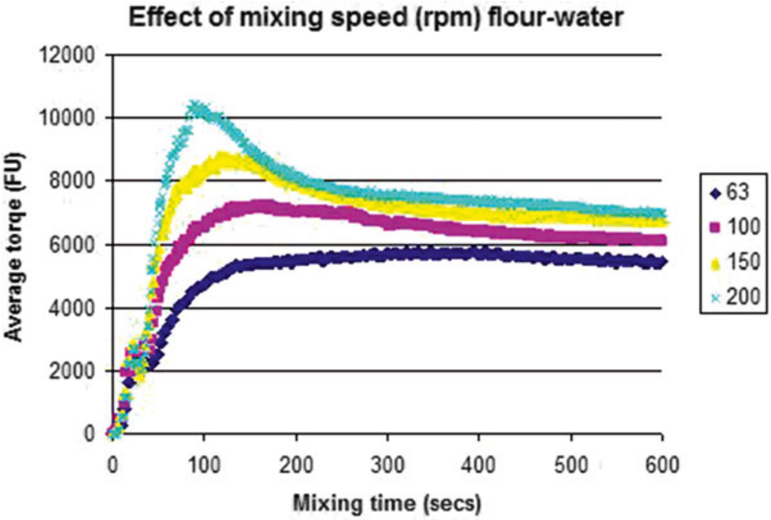

Fig. 7.2 Perten DoughLab flour-water dough mixer torque traces at different speeds (Courtesy *BakeTran*)

Even when the automatic collection of mixing data is not possible, valuable information can be gained from records of the main ingredient and final dough temperatures available. If ice is used in the mix there should be a note of the level of addition. From such data it is possible to calculate the approximate level of energy delivered to the dough for any given mixer and mixing conditions (Cauvain and Young 2008). If a cooling jacket is fitted to the mixer it is not a difficult job to determine the effectiveness of the coolant and to incorporate such information in the

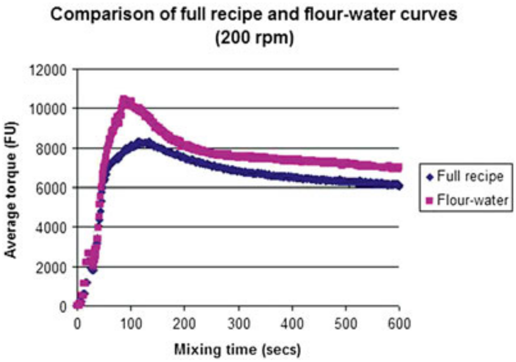

Fig. 7.3 Comparison of flour-water and full recipe dough traces in the Perten DoughLab (Courtesy *BakeTran*)

calculations. The assessment of energy delivered to the dough during mixing is invaluable in understanding dough development and therefore the gas retention capabilities of the dough (see Chap. 2).

Dough Divider Performance

If there is one piece of equipment where data has been and continues to be extensively collected it is at the check weigher associated with the divider. There are both practical and commonly legal reasons for continuously monitoring the output from the divider. Bread is often sold by weight and in many parts of the world there are mandatory weight controls which are applied at the point of sale. As this is often the case then bakers need a means to ensure that they do not breach any legal requirements. A common form of the legislation is based on a minimum weight at point of sale and by measuring the weight losses experienced by the processing of the dough piece to the loaf at point of sale, bakers are able to decide the scaling weight that is needed at the dividing stage.

In practice the bakery will have a range of dough piece weights which are designed to deliver the minimum loaf weight at point of sale. The range will depend on many factors including the type of the divider and condition of the dough. The divider weight check is a useful way of minimising ‘give-away’; that is providing a mass of bread to the consumer beyond that required by law. It is not just the mass of dough (bread) which is given away by unnecessary heavy weight dough pieces but also the cost of energy in baking the product. It is a common practice to automatically reject underweight dough pieces to avoid the potential for prosecution though the same thinking is not applied to over-weights. In considering how to use check weight data in the bakery it is useful to remember that loaf height (and other quality characteristics) are related to the mass of dough in the unit. For example, if the final loaf has excessive height ex-oven, a first check ought to be that the loaf is at the correct weight.

A further benefit of using check weight data to narrow the range of dough piece weights and so reduce ‘giveaway’ is to increase the yield of product from a given batch of dough and thereby make a positive contribution to the profitability of the bakery (Wilson et al. 2005). The contribution to bakery profitability is compounded by the fact that more loaves will enter the oven to be baked and energy cost involved in baking a loaf may fall. A similar benefit will be gained in cooling if dough piece weight is optimised to deliver optimised bread weights.

Dough Processing

The equipment used to process and shape the dough pieces will have a series of settings and indicators for things like gaps in the sheeting rollers in the final moulder. These should be standardised for a given size and type of dough piece and variations from the norm recorded to provide data which can be used to identify solutions to quality problems, e.g. the sources of poor cell structure and unwanted holes in the crumb.

Proving, Baking and Cooling

All of the equipment involved in the proving and baking of dough and the cooling of bread will have a range of set conditions and forms of indicators of the relevant conditions being delivered. As with all other pieces of bakery equipment deviations from the norm should be recorded. It is common practice to monitor the performance of equipment in these areas with some form of recording device. In the case of provers this would entail temperature and relative humidity, temperature in the oven and temperature and perhaps relative humidity in the cooler.

In the past the practice has been to monitor oven temperatures, not only to ensure that the set conditions are being delivered but also that the conditions are being delivered uniformly in the oven, particularly across its width. Increasingly oven performance measurements are being based on heat flux as this is a far better indicator of the quantity of heat being delivered to the product.

On-Line Measurements

Currently there are few opportunities to carry out on-line measurements in the bakery. Dough piece weight has already been commented on. Today on-line measurements have been extended to include loaf height and shape and crust colour. While these have become increasingly common there have been few attempts to integrate such data with other process measurements for the purposes of process control.

Off-Line Measurements

The off-line measurement of bread qualities has been practised for many years and some of the quality characteristics concerned have been discussed in Chap. 1. Occasionally dough rheology data are captured off-line but the practice is not common.

Some product quality parameters remain difficult to contemplate as an on-line measurement. In particular, the measurement of the features which characterise the internal structure of baked products. As discussed in Chap. 1, assessment of the internal structure of a fermented product remains firmly based on subjective methods, albeit carried out by experts. Objective measurement techniques are now available (e.g. C-Cell) but they still require the removal of samples from the line for analysis.

The Integration of Collected Data and Its Analysis

There are many ways of analysing process data which may be collected in a bakery. In its simplest form it may consist of process control charts which record individual measurements and plot them on charts on which the operating limits are defined. This quick visual check allows bakers to follow production trends and to associate changes in process behaviour and product quality with variations in ingredients and recipe.

One of the important considerations that must be applied when trying to identify the causes of quality changes or the effect of new ingredients is to ensure that data sampling points are associated with the production timeline. In baking it is commonly several hours after the dough has been produced before the quality of the final product is observed. Further complications arise with the overlap of batches and the inter-mixing which may occur when single provers and ovens are fed by more than one mixer or processing line. This may seem to be a statement of the obvious but it is not unknown to assume that two mixers or processing lines are delivering identical dough pieces to the prover.

Since on-line measurement and automatic data capture are uncommon in bakeries, it is difficult to establish a process model which can be used to optimise plant efficiency and product quality. One difficulty is that baking in most cases can be defined as a batch-fed continuous process. In industrial bakeries once a batch of dough enters the divider the intention is that all subsequent process equipment will be continuously filled with dough and bread—at least within a given production run for a given product type. This means that batch intermixing is bound to occur to some extent. Added to this is the complication that dough is constantly changing in part because of changes in the intrinsic dough rheology (Chap. 11) and in part because of gas production by the yeast.

Process control software does exist which allows the visualisation of complex processes and the identification of important relationship in optimising process efficiency and ensuring consistency of final product but its application in baking remains limited. In part this is because we have still to identify what we need to measure and in part we still do not understand sufficiently well what controls final bread quality.

Applications of Knowledge-Based Systems

Achieving quality products consistently, whether new or existing ones, must be the goal of any baker wanting to remain in or improve the business. Computer programs which can advise on recipe formulation, on optimal equipment operation and assist in perfecting a faulty or substandard product can be useful tools for the bakery technologist involved with product development and quality optimisation (Cauvain and Young 2001). However, such programs cannot be developed unless the knowledge exists about the technology of the product and is made available. Embedding knowledge into a computer program requires a different approach from that used for the development of spreadsheets and databases. The systems used are commonly called 'knowledge-based' or 'expert' systems.

An **expert system** may be defined as a computer program that seeks to model the expertise of a human expert within a specific domain and a **knowledge-based system** (KBS) embodies heuristic knowledge (rules-of-thumb, best guess, etc.) captured from intelligent sources.

It is easier to consider how KBSs differ from data and information processing, using an example as follows. If a baker has a recipe with ingredients and quantities then using a data processing program the cost of the recipe can be determined simply by multiplying the unit quantity cost by the quantity of an ingredient and then summing all the costs of all the individual ingredients. Each time a new recipe is input the calculations can be done and the route or set of logic/numeric equations executed by the program is the same. If the baker then follows a recipe and processing method, say for pan bread, and finds that the product is faulty or below specification, then in order to obtain some advice for corrective actions any computer program that the baker uses must contain some rules and facts about the ingredients, the processing and the combination and interactions between them. When another recipe, perhaps for rolls instead of pan bread, is input to the program, the path and sets of rules will be different. The route through such programs can take many paths. Each path is determined from information given and decisions made by the user and the knowledge contained and defined within the system. An explanation of the reasons behind the conclusions reached by the program and corrective action for rectifying the problem can be given to bakers.

In order to develop programs which can deal with the technology of the product, that knowledge must be available and be accessible (Young 2005). Importantly the integrity and validity of the knowledge must be sound. There are different sources from which the knowledge can be gathered. First, there is knowledge in the form of the written word together with the numerical data to support it. Second, there are the human sources—the experts. For example some of the methods which are typically used to assess bread characters have been described in Chap. 1 but assessment of bread quality, whether subjective or objective, has no value unless the user has the ability to change bread character in a particular way. Traditionally this is a role for an 'expert'. Experts are sometimes hard to find and when they are found the very fact that they are recognized as experts inevitably means that they are busy people.

The knowledge, once captured and structured into a KBS program, can be used by technologists with different levels of skills. Whether used by an expert or novice, the KBS never forgets or becomes tired, and the advice or information returned to the user is consistent. From that information, users can learn and expand their own knowledge of the baking technology concerned.

The areas where KBSs have been most successful in the baking industry have been in advisory and fault diagnostic systems (Cauvain and Young 2006a). The first important criteria is that the 'domains' or subject areas must be well defined before such systems are developed. Attempting to produce in one system a tool which covers the whole of a subject area is a mammoth task and will probably be doomed to failure. It is better to take a domain and split that domain, say bread technology, into manageable chunks. These chunks can be linked together to form the larger picture. The second important criterion when developing such systems is that the knowledge should exist and be sound. Where experts are used to provide the knowledge input and where there may be conflict between experts in the knowledge given then care must be taken in sorting the 'fact' from the 'opinion'. In many instances there may be a case for performing further work to determine the facts to support the existing knowledge.

With advances in software programming languages and in the platforms in which they operate, encoding the knowledge has become much easier. However the structuring of the knowledge for such purposes is still as important as ever. The systemization of knowledge has to be done before encoding can start and can be used independently of the software if the funds for programming are not available. The user interface or dialogue is designed to make the querying of that knowledge easy and meaningful to the user.

Examples of Knowledge-Based Systems

In the past the thrust for developing KBSs in the bread field came from first the Flour Milling and Baking Research Association (FMBRA) based at Chorleywood, UK, and later from the Cereals and Cereal Processing Division of the Campden and Chorleywood Food Research Association (CCFRA). This division continued the cereals-based technological function of FMBRA when it merged with Campden Food and Drink Research Association in 1995.

In 1990 a Bread Faults Expert System (Young 1991) was released. Its knowledge domain was white pan breads made using the Chorleywood Bread Process (Chap. 2). Its original research objective was to determine whether the knowledge-based systems area of computing science could be applied for the benefit of the baking industry. The potential for such systems was soon realized and the objective was extended to produce a commercially available computer program for the industry. The knowledge of faults was underpinned with baking trials and the manifestations of the faults were recorded photographically. These photographs were included in a manual which accompanied the system. When this system was developed in 1989, the expense of including these images in the computer-based system would have been prohibitive in cost and hardware memory.

Computer science advanced quickly after the first systems were developed and that along with the falling cost (in real terms) of computer hardware saw the development of such systems in other domains of baking technology: the Cake Expert System (Cauvain 1994) comprising Fault DoC (Petryszak et al. 1995), BALANCE (Young et al. 1998, 2001) and ERH CALC™ (Jones 1994). With these advances in computer science and the advent of the Internet, the potential for using knowledge systems was further realized by the development of a Bread Advisor, a natural extension of the Bread Faults Expert System with the domain widened to include the technology of producing a variety of fermented bread types by five processing methods, making the software a tool for use in many countries around the world. The Bread Advisor (Cauvain and Young 2006b) was developed as both a stand-alone software system to be used like any other computer program on a desktop or portable pc, and as a 'back-end' program for use from a pc acting as a server with all that this enabled—multi user access either from within a baking company or via the Internet. The latter, however, was only implemented as a demonstrator system.

Product Optimisation

Using the Bread Advisor as an example we can follow how such a tool might be used. First, the product type and processing method is chosen to define the domain. During a consultation, these choices define a product profile which is built and carried forward to other parts of the system. If the purpose of the consultation is for fault diagnosis or for improving the product quality, then the more information about the product that can be given to the system, the more accurate the ultimate diagnosis can be. If conflicting pieces of information are given the system will tell the user and ask for some information to be re-submitted. In this way the Bread Advisor 'mimics' the way a human might diagnose a fault or set out to improve the quality of the product in that we identify the problem, try to ascertain the causes, gather information to eliminate them and then consider the options for corrective action or improvement for the most likely causes of the fault. On many occasions the manifestation of a particular fault or defect does not necessarily have a unique and identifiable cause and so there may be other intermediate steps to take into account in determining the real cause of the problem. This logic flow can be described schematically as follows:

PROBLEM → PRIMARY CAUSE → CONTRIBUTING FACTORS → CORRECTIVE ACTION

Or in more simple terms as:

What is seen → why → because of… → corrective action

Using this approach, the first step is to choose the fault or quality attribute for improvement. In the Bread Advisor the faults are divided into categories. These are diverse and include aroma, crumb (faults which occur inside the product, e.g. holes, texture, structure, colour etc), dough (faults which occur during the processing of the dough, e.g. sticky or soft dough), eating qualities (for both crumb and crust), flavour, shape (e.g. concavity, low shoulders, lack of oven spring) and surface (e.g. crust colour, spots, blisters and wrinkles. Faults or product quality deficiencies rarely have a single cause. However they can be split into those which are considered 'primary' or principle causes (the 'why') and those which have 'contributed' (the 'because of…..') to the faults in question. The causes may be ranked in order of likelihood, the most likely being listed at the top of the diagnostic list. The list of primary causes can be considered and checked against the processing conditions which occurred. Any factors which might have contributed to these primary causes can be displayed when the cause itself is checked and the 'Contributing factors' button selected. At the end of a consultation the baker has a 'suspects' list which can be considered along with the local conditions that the product underwent during processing in order to dismiss or confirm the causes of the fault. Following this the necessary corrective action can be taken to improve the product quality.

For an experienced baker, the fault diagnostic aspect of programs like the Bread Advisor consider all the necessary information and offer quick and thorough investigations. Unlike a human, the software never forgets or overlooks a possible cause. For less experienced bakers and technologists, the same aspect offers knowledge about the causes of faults from which they can build their own knowledge base on bread faults. Suspects can be eliminated quickly when processing conditions are checked or the 'once in a life time' fault is flagged for investigation. Investigating the 'suspects' can also be undertaken with the software. By inputting known processing details about operations such as mixing their applicability can be checked for acceptability for the product in question. The generic settings given by the software are only those relevant to the process chosen. Where the input values for the mixing stage are at variance with the requirements for the process and product, information is displayed giving the range of values in which the parameter should lie to achieve acceptable product quality. Such information is useful in isolating the cause of the fault and to the novice who may be unsure of the settings required for a successful product.

A KBS which provides an objective diagnosis of bread products can also be structured to answer questions, e.g. through questioned using 'What if I…' route. This approach can be valuable for understanding the breadmaking process whether for attempting to change the quality of a product or improve it or to explore a new product concepts. Questions could be posed about any of the processing steps and the parameters contained within the step. Comments about the effect on the product if the directional change could be displayed. The ability to experiment about breadmaking at the pc provides a valuable training tool. The novice technologists/bakers can learn at their own pace, and can try out ideas before committing to full scale development of new products.

Production Control with Knowledge-Based Systems

Controlling production has been an area where KBSs knowledge based systems have been slowly adopted in the food industry though at-line control has been attempted to some degree. For example, a Retarding Advisor (Young and Cauvain

1994) was developed to demonstrate to the baking industry the use of knowledge-based software to link to and control the operation of bakery equipment—in this case a retarder-prover. As described earlier (Chap. 6) the retarding process for fermented goods allows bakers to 'time-shift' production to meet peak sales demands, eliminate night working and to give staff more sociable working patterns. The Retarding Advisor enabled bakers to achieve acceptable and consistent product quality when using a mix of products configurations. It encompassed the types of information on the interaction between product, recipe and process conditions as described in Chap. 6. It advised the baker on the appropriate settings required for the retarding equipment according to the mix of products. It determined the start and stop times for both the cold (retarding) and warm (proof) phases of the process in the retarding cabinet. The complex relations between ingredients, formulations and between temperature, time, yeast level and bulk of dough in the cabinet were taken into account to give bakers the optimum settings for the products to be retarded. These settings could be down-loaded to the cabinet. In addition to the at-line control, the Retarding Advisor could be used off-line to explore of the reasons of poor quality by use of a detailed fault diagnosis with corrective actions indicated. The system had particular relevance not only to bakeries which use retarding equipment but also to equipment manufacturers and ingredients suppliers.

Information could be passed not only from the pc to retarding equipment, but also can be received by the PC from that equipment and further processed in the light of rules that apply to the equipment and the retarding technology in question. This processing information could provide indications of the performance of operation of the equipment and as a monitor for preventative maintenance of the equipment. This can lead to less downtime for the equipment. Development of the system also led to improvements in the control systems of current retarding equipment. Where throughputs for product are known, they can be linked to the scheduling requirements to supply quality products for a changing pattern of customer demands as is often experienced in supermarket in-store bakeries.

Production Scheduling (ROLLOUT)

Every bakery, whatever its size, has to plan and schedule its production efficiently if it is to make the best use of its equipment, keep costs under control and customers happy by delivering products of the expected standard at the right time. Whether fermented products are being produced in a plant bakery or the more modest sized craft or in-store bakery, the timings and capacities of the equipment to be employed all have to be taken into consideration so that there is smooth transition, with few or no gaps, from one part of the process to the next. When the requirement for pans and trays, and for product to be ready at specific times of the day is considered the complexity of the task of scheduling is soon realized. Being able to visualise how the production flow dovetails together is no easy task and often conflicts arise during the processing sequence. For example, in an in-store bakery if scheduling is not accurate product quality can easily be compromised when oven capacity is not available while in plant bakeries, runs/batches might have to be re-scheduled at a moment's notice because of equipment breakdown, or a change in the priorities of the ordering sequence.

To address such problems a consortium of plant, craft and in-store bakeries worked together with cognitive scientists at Sussex University to develop a software system, known as ROLLOUT, was developed which 'visualised' the complex subject of bakery scheduling (Williams 2006). The system comprised a 'planner' view and a 'scheduler' view. In the planner view the orders for customers or for a particular time window or deadline could be created. The orders specified the types and quantities of product required and were placed in the view at the approximate deadline time. The mixes/batches required to fulfil the orders could then be populated automatically into the scheduler view. Knowledge about the equipment capacities for each type and size of product along with process stages and their timings were brought into play in populating the scheduler view. The scheduler view comprised cascading horizontal bars (Fig. 7.4) (the length depicts time while height depicts capacity usage for the equipment at the process stage) imposed on a continuous timescale for the day's production. Conflicts which might occur, e.g. oven capacity insufficient or two products reaching the same process step at the same time, were flagged and highlighted in red. The scheduler/baker could re-arrange these 'cascading' production process runs so that the conflicts were eliminated. The powerful aspect of this software was the visualization on a pc screen of a complex problem and the opportunity for the baker/planner to manipulate the schedule to meet the goals of the bakery business whether that be fresh products of the right quality available at specific times of the day, efficient use of valuable plant time or many other goals.

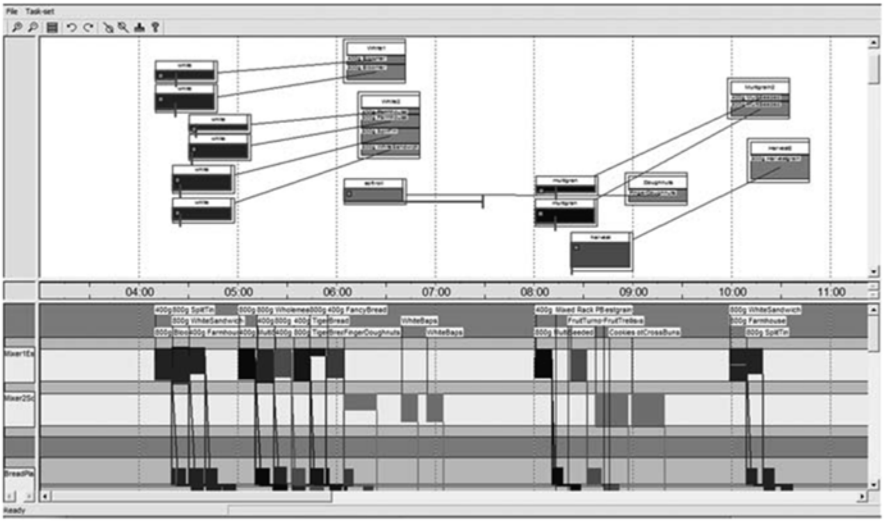

Fig. 7.4 ROLLOUT example screen

Conclusions

Knowledge-based systems can be a useful computing technique for application in the baking industry. There have been cases where they can be used 'solo' as diagnostic tools or advisors to provide objective, supportive tools in an industry where the pool of expert resources continues to diminish. They provide a lifeline to hard-pressed product developers (Young 2004) enabling them to innovate from a basis of sound knowledge and efficient software tools with which to achieve their goals. In a training environment they facilitate the uptake of and experimentation with knowledge about baking technology and processes. They provide easy access to focused and appropriate knowledge about fermented products for an emerging generation of bakery technologists who are computer literate and at ease when using computers as tools in the workplace.

Their greatest potential lies, however, with their integration with other computing environments, systems and techniques, for example with spread-sheets and databases, with on-line integration to equipment and with other advanced techniques, such as neural networks and fuzzy logic, to provide a limited element of artificial intelligence. In many computing scenarios in the baking industry the processing of 'data' in an ordered pattern is no longer enough to provide the solutions to the problems facing the industry. The data have to be linked to the technology of the product and to the rules, facts and techniques which determine how that data can be best applied to provide the solutions for the production of baked products. For example, the patterns seen in the slice of bread captured by the C-Cell instrument (Chap. cc) and the data which determines that structure might be linked via a knowledge system to detect trends in the product quality and to the correction of the settings on the plant to prevent faulty or sub-standard products reaching the customer. In some cases the knowledge could be embodied within the system while in others the knowledge may be called up and 'bolted in' as required.

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Chapter 8
Baking Around the World

Introduction

Why is it that 'bread' means different things in different parts of the world? Place a loaf of white North American pan bread beside a loaf of Central European rye bread, Middle Eastern pita bread or Chinese steam bread and it could justifiably be said that they are all quite different products. Yet they are all classified as bread. Why do bakers in different parts of the world use quite different recipes, equipment and processing methods to make the same, or almost the same, product?

To be able to answer these questions and hence better understand baking in Europe, Africa, North America, Australasia and Asia, it is first necessary to appreciate

- The historical development of breadmaking.
- The factors which influence the process of breadmaking.
- Customer expectations.

History

The breadmaking process is the interaction of raw materials, equipment, procedures and people in a particular environment. The end product which results from this interaction depends on the characteristics of each of the process components. It will also depend on customer requirements and expectations. Historically, the most dominant of the process components have been the available raw materials (especially the wheat) and the environment. Over the centuries, and particularly in Western countries, the nature of bread has changed with the evolution of modern wheat varieties, the processes by which they have been converted into flour, and the numerous technological advances in baking itself.

S. Cauvain, *Technology of Breadmaking*,
DOI 10.1007/978-3-319-14687-4_8

The evolutionary path of bread baking wheat from the primitive parents *Triticum boeuticum* and *Triticum dieoccoides* has been different in different parts of the world. These differences have resulted mainly from variations in climate, soil, agronomic practice and culture, though in more recent years other environmental aspects, such as the economic, industrial and scientific factors, together with political developments have had significant effects. Because the evolution of wheat has occurred in different ways in different parts of the world, so the nature of bread has evolved differently in various countries and regions. Faridi and Faubion (1995) classified the different breads of the world in this way:

- Those with high specific volume, such as the pan breads of the UK, North America and other Western countries.
- Those with medium specific volume, such as French breads and many rye breads.
- Those with low specific volume, e.g. flat breads of the Middle East and Eastern countries.

Each of these breads has its own particular characteristics which have resulted from the differences in ingredient-recipe-process interactions referred to earlier and which underpin all breadmaking processes.

A sample from a shipment of wheat from Danzig in the Baltic is attributed as the forerunner of the vast wheat industry of North America (Bailey 1975). What is most noteworthy about that event is that a wheat from an area not now known as delivering ideal wheat for breadmaking found a true home in North America and set the standards not only for future generations of wheat but also dictated the type of bread which was to become the standard for Canada and the USA, with of course some regional differences. Thus it is seen that an ordinary wheat from one part of the world became a much better wheat in the New World. This wheat was known as Red Fyfe after the farmer who first grew it in Canada.

This transition is an example of the chance development of wheat which occurred from the early days of cultivation until the latter part of the nineteenth century. Since then, scientists have used the principles of genetics and have developed many variations of wheat to suit the needs of particular areas. More recently, particular types of bread and other flour-based foods have resulted from new wheat varieties. Red Fyfe was to be one of the parents of what has been described by Professor Boyle of Connell University in the USA ‘As the greatest single advance ever made in the United States.’ Boyle was referring to the Maquis variety of wheat which had been bred in Canada by Sir Charles Saunders in 1903 (Bailey 1975). Special mention has been made of these developments in Canada because of the standing and influence of Canadian wheat on the world wheat market. For over half a century, Maquis became the standard by which bread wheats were measured, not only in North America, but also in most Western countries. Cereal breeders in other parts of the world have not necessarily had the same ideal circumstances to work with as were prevalent in North America. In particular, the climate and soil have imposed limitations on the extent to which hard-grained high-quality bread wheats can be consistently grown. The consequence of this has been a continuation of the production of bread-type wheats which originated in north America.

In more recent times a similar approach has been used in the UK where a Canadian wheat variety has been adapted to grow under UK environmental conditions. There are a number of potential technological advantages to this approach, the most obvious one being an increase in the available protein. However, it is just as likely that the approach was driven by commercial imperatives such as reduced transport costs (fewer food miles and a smaller carbon footprint in modern jargon) and by the potential marketing advantage of being able to claim 'made with 100 % wheat'. After a successful introduction into the UK the impact of environmental conditions was felt in a subsequent year when many UK wheats suffered from low Hagberg Falling Numbers which reduced the likelihood of manufacturing bread from 100 % UK wheat. This example is a perfect illustration of how the ingenuity of humankind can still be foiled by the vagaries of nature.

It should not be forgotten that consumer preference is likely to have a significant influence on wheat breeding programmes. Sidhu (1995), when writing of wheat breeding in Pakistan, quotes 'Chapattis which have a creamy-white colour, soft silky texture and sweet wheaty aroma are preferred by the consumers'. This example and those from other countries wheat breeding programmes are accordingly oriented to select wheat varieties conforming to the desired consumer traits. However, with the advent of modern communication, travel and trade, bread varieties originally confined to a particular area are now made in many countries of the world, and examples of this type of cross-culture in bread are provided by Qarooni (1995). This movement of bread types between countries and cultures can pose problems for bakers. For example, the manufacture of French bread may be considered a challenge to bakers outside France. This is a challenge which can be overcome but does need an understanding of what makes French bread the product that it is. In Table 8.1 it is notable that those countries where French bread is popular are those countries with a French colonial presence in the late nineteenth and early twentieth century. Significantly, some of the best French bread in Australia is made by immigrant Vietnamese bakers who learned their craft from their former French colonial masters. The special qualities of French bread are said to be due to the flour, the water, the yeast, the ovens, the atmosphere, the temperature, the Eiffel Tower, the aroma of coffee and Gitane cigarettes, the temper of the femme de boulanger and of current politics (Bailey 1975). This statement will be examined later in the light of modern thinking about the baking process.

An historical aspect of bread baking which perhaps still has an impact on today's thinking about bread is that of adulteration (Marchant et al. 2008). Particularly in Europe and the UK, the histories of bread make reference to various practices of economically hard-pressed millers and bakers adulterating flour and bread with chalk, rye and alum, bean meal, slaked lime and bone ash. In Roman times, bakers were accused of adding a whitening agent to their bread. It is thought that this may have been magnesium carbonate. The accuracy of these accusations is somewhat doubtful but then, as now, the public seemed to want to believe the worst of bakers. Bailey (1975) attributes most of the reasons for adulteration to the economic pressure placed on millers and bakers and the perception that white bread was seen as being preferable to the dark (by today's standards) bread produced from the so-called white flour then available to them.

Table 8.1 Popular types of bread in Asian, Middle Eastern and North African countries (Qarooni 1995)

Country	Bread type
Afghanistan	Naan, Chapatti and European bread
Algeria	Matlowa, French bread, Khobz El-dar, European bread
Bahrain	Tanoor, Arabic, Chapatti, European bread, Samoon
Djibouti	Kisra
Egypt	Baladi, Shami, Samoon, French, Fatier, Shamsi, Bataw, European
Iran	Barbari, Tanoor (Taftoon), Lavash, Teeri, Suage, Sangak, European, French
Iraq	Tanoor (Khobz), Arabic, Samoon, European bread
Ethiopia	Injera
Israel	Sadj, Tarboon, Kimaj (Arabic), European bread
Jordan	Armani, Mafrood, Sauj, European bread
Kuwait	Tanoor, Arabic, European bread
Lebanon	Lebanese, Suaj, European bread
Libya	French bread, Arabic
Morocco	Moroccan Khobz El-dar, French, European
Oman	Arabic, Tanoor, Chapatti, European
Saudi Arabia	Samouli, Mafoud, Tannouri, Burr, Tamees, Korsan, European bread
Somalia	Injera
Sudan	Injera, Shamsi, Baladi
Syria	Mafrood (Arabic), Armani, Samoon, Suaj, European
Tunisia	Trabilsi, French bread
Turkey	Balzuma, Gomme, Yafka, French and other European bread
United Arab Emirates	Tanoor, Chapati, Arabic, Samoon, European
Yemen	Roti, Malouge, French, European bread

When attitudes towards bread are considered today, little has changed. White bread has to be white. Some bakers still use some additives to achieve this though the list of permitted additions is much reduced. In most countries, regulatory standards, combined with today's sophisticated analytical techniques, ensure that the ingredients in bread are beneficial, not just to the baker, but also to consumers. Old attitudes die hard, though, and bakers and the baking industry still have an incomplete public relations task to convince consumers that today's bread is one of the safest food products on the shelves of the corner store or supermarket.

The claim by Bailey (1975) that adulteration in the early nineteenth century in the UK was the result of 'the desperate intense competition between bakers following the abolition of price fixing in 1815' also rings a bell when the market-places of today are considered. The problems associated with competition between bread bakers and the inevitable move in some cases to finding ways of making and selling bread at a cheaper price compared with other bakers is not confined to the major bread markets of the world; the same situation quickly arises in emerging markets, like Indonesia, where bread consumption quickly begins to rise. To the environmental and cultural differences which have influenced the type of bread predominant in a particular country has been added the consequences of the various waves of refugees and immigrants which have moved between countries. Reference has already been made to the Vietnamese in Australia. Other examples are easy to find, not only in Australia, but in many other countries, of how emigrant people of different nationalities have influenced bread types in their new homelands with ideas from their personal histories.

One of the most important examples of industrial progress which influenced the type of bread being produced was the introduction of roller mills to flour milling in the mid-nineteenth century. Only with this introduction could flour be produced which was largely free of the bran and germ, the main contributors to darkness of the so-called white bread previously produced. Facilitating as it did the more efficient removal of bran and germ, the advent of this flour milling process was also the first significant step on the way to producing bread with the keeping qualities expected of today's packaged bread. Other steps along this road have been the result of the application of science to breadmaking, which began in the late nineteenth century. These included better wheats following scientific breeding, oxidizing agents such as potassium bromate, refined fats, then emulsifiers, and followed later still by enzymes (see Chap. 3 for discussion on functional ingredients). All of these have only been made possible by improved scientific understanding of the breadmaking process. Folklore has gradually been replaced with scientific fact which, together with the improved ability to control the process, allows the production of the consistent product seen in most supermarkets. Just as the Industrial Revolution provided the steel for the roller mills, so did it provide the steel for the first modern mixing machines and other bakery equipment. Of course, this equipment also needed the power to operate it—first this was steam and later electricity. To those people working in today's modern industrial bakeries it is difficult to imagine that, what is now seen as essential to produce a product to satisfy present customers, 100 years ago had not even been heard of.

Other environmental factors which have changed the nature of bread, particularly in Western countries, are methods of distribution and the advent of the supermarket, superstore and the convenience store. While the supply chain has lengthened and the time from oven to table has extended from minutes to hours or days, customers still expect their bread to be soft and palatable, i.e. 'fresh'. To achieve this the original flour, water, yeast and salt has, of necessity, been supplemented with a variety of 'improvers' and wrapped in a series of specialized packaging films. With this background it is appropriate now to consider the breadmaking processes around the world in some detail.

The Breadmaking Process

Whatever type of bread is made around the world, to ensure that it is of acceptable quality to those who eat it, it is essential that the interactions between the various parts of the baking process are compatible and in balance with each other.

The extent of the balance established between the raw materials, procedures and equipment determines not only the quality of the end product but also the consistency of maintaining that quality. Craft and artisan bakers, whether they are in a peasant home in India or in the village high street in England, achieve this balance by subtle alterations to what they do as they proceed through the process. In contrast, the constraints inherent in automated mechanical baking dictate the need for sophisticated quality assurance systems to ensure consistent product quality.

Raw materials, particularly flour, which produce an acceptable or even superior product in one part of the world may not do so when used under different circumstances in another country. Similarly, equipment developed for producing Western-type pan breads in one country may need considerable modification or the addition of supplementary equipment to produce the same type of bread using different flour, or indeed the same flour under altered environmental conditions. There have been many instances where a failure to recognize these factors has resulted in unsatisfactory performance in bakeries and frustration for all involved. In order to understand why this is so, it is necessary to understand the basic processes of baking and how these apply in the situations which prevail in different countries, when different products are being made, or where different environmental conditions apply. When considering this approach it is necessary to start, not with the raw materials or the equipment, but with the question 'who are the customers and what do they want?' If the customer is a supermarket shopper in the UK looking for a loaf of bread with which to make sandwiches for lunch the following day, that person will be looking to buy a product which is already sliced, which will still be soft and palatable at lunchtime tomorrow, which can be spread easily with butter or margarine without coming apart (flexible crumb). Not only this, but any leftover bread should freeze and retain the above properties when thawed. In addition, if it is not used for sandwiches, it should brown evenly and quickly when toasted. Compare this with the expectations of villagers in India and Pakistan when they make their own chapattis, or less commonly, buy them from a local baker. Sidhu (1995) states 'Probably the consumers of chapatti in Pakistan have not yet abandoned the age-old concept of using their product fresh from the hot plate (baking griddle).'

The same author also stated that 'the two most important quality parameters for chapatti (in India) are softness and flexibility.' Such properties are remarkably similar to those required by the UK consumer of sandwich bread. Thus two extremes of breadmaking sophistication have as their main quality characteristics softness and flexibility. At one end of the scale this is achieved by refining the raw material, processing to a high specific volume (giving a soft product to start with) and retarding the staling process by the addition of various anti-staling agents. At the other extreme these properties are achieved by eating the product immediately it is made. However, in both instances it is necessary to have the right type of wheat with which to start the process. Sidhu claims that more research is needed into the popularization of commercially produced chapatti and other baked products in Pakistan to produce a product with the same characteristics as that straight from the griddle. In attempting to understand these extremes of breadmaking sophistication, it is also relevant to consider other factors which are basic to breadmaking, irrespective of the type of product. Sidhu gives a flow chart for chapatti preparation and after adding water to flour the next step is described as ‘mix into smooth dough’. There is a clue here to one of the fundamentals of breadmaking that is universally important, namely dough development.

Flour and Dough Development

The extent to which dough should be mixed and developed depends on the type of flour available, the subsequent process steps, as well as the characteristics of the end product. Note there is no reference here to any testing method. Rather it is end product quality which should determine the required amount of development in the dough and its interaction with the processing steps which follow mixing.

North American breadmaking wheats require considerable mixing to achieve optimum development as defined by the end product characteristics. This is true even if the mixing stage is followed by a period of bulk fermentation. If the fermentation stage is reduced, or even eliminated (no-time dough), even more development is required at the mixing stage (Table 8.2). It should be noted that, according to Faridi and Faubion (1995), the three different processes are used in different circumstances and the end products may be somewhat different. However, to achieve the same result in the same product, using the same raw materials, it can be assumed that the shorter the fermentation time, the longer the mixing time required (this equates to the delivery of more mechanical energy to the dough). Bread baking flours in countries other than North America often require shorter mixing times than their North American counterparts.

Similarly, users of the Chorleywood Bread Process (CBP) find that the wheat varieties from different countries require different levels of work input to achieve optimum development. Difficulties can arise when this is not understood and major changes are made in a mill wheat grist. For example, if a mill changes from locally grown wheat to imported wheat without taking into account the requirements of the bakery, significant changes in the mixing requirement (work input) can result. Similarly, the writer has observed instances where the CBP has been installed in a bakery without an understanding of the available raw materials and has not delivered the required end result. This has been observed in practice when the local flour comes from North American wheat with an optimum work input of 20 W h/kg. As the temperature of the flour was usually about 30 °C in tropical countries there

Table 8.2 Processing conditions for North American wheats (Faridi and Faubion 1995)

Process	Total mixing time (min)	Total fermentation time (h)	Cysteine added (ppm)
Sponge and dough	15–17	3–5	
Straight dough	16–21	2	
No-time straight dough	16–21		40

is often little chance that optimum development can be achieved while maintaining dough temperatures of approximately 32 °C. Significant flour cooling equipment may need to be installed to overcome the problem—the alternative is for underdeveloped dough with a significant reduction in product quality. T.H. Collins, one of the inventors of the CBP (personal communication, 1993) has described such flours as ‘awkward’. However, it is only awkward if it is being used in bakeries where the process has been designed without taking into account the nature of the available flour. The presence or absence of other ingredients in a dough can also affect the amount of mixing required to suit the process. This has been demonstrated where the use of potassium bromate has been discontinued in countries using the CBP. If ascorbic acid is used to replace potassium bromate in a no-time dough, a buckier and apparently less developed dough results at the moulding stage. To overcome this, mixing, or development, need to be increased; the extended mixing time (energy input) delivering a dough which now has a rheological character which makes it suitable for subsequent processing by the chosen processing method.

Related to the need to identify the correct mixing required for optimum development are the methods used for testing flour. Skilled craft bakers the world over may be able to adjust their processes to take into account variations in raw materials and the environment. However, in today’s environment, where consumers expect consistency in product quality, such an approach is inappropriate for industrial plant bakeries. In these situations the ability to control the total process within clearly defined parameters is an essential prerequisite to producing bread of consistent quality. A logical consequence of this is that the performance characteristics of raw materials must be known before they enter the bakery. This being the case, attempts to establish international standards for flour testing, which do not take into account the process being used have limited value as predictors of absolute quality or performance. Such international standards have their greatest value where wheat is being traded around the world since they allow both seller and buyer to make a reasonable assessment of the suitability of a given wheat variety for use on its own or as a component of flour millers grists.

While it is true that good bread baking flour can always produce good bread, it can only do this if it is treated in accordance with the functionality in the process being used. This has not always been recognized and when purchasing and milling decisions rely on so-called traditional flour testing methods, there is no guarantee that the end product quality will reach the required scientists. New Zealand bakers and scientists recognized this soon after the introduction of the CBP into that country (Waters et al. 2013). Flours which were available there for making bread in the late 1960s and 1970s often only required half the work input that had been advocated by the originators of the process. The recognition of this led to a method of flour testing which closely approximated the CBP (Mitchell 1982), a method which bakers in that country could confidently rely on to predict the performance of flour in their CBP-equipped bakeries.

The popularity of the CBP in countries like New Zealand and Australia is, in no small part, due to this ability to predict flour performance accurately, but also to the fact that it was introduced to New Zealand for the same reasons underlying its adoption in the UK and many other countries today; namely, the ability to maintain existing bread quality while increasing the proportion of locally-grown wheat in the flour miller's grist (Cauvain and Young 2006). Today, 80–90 % of packaged bread is produced by the CBP in the UK, Australia, New Zealand and South Africa and the proportion of bread being made this way in other continues to increase. The close relationship between the CBP and home-grown wheat varieties has continued and today in the UK and elsewhere local-grown wheat varieties typically constitute over 70 % of milling grists, and sometimes 100 %.

Consistency of quality can also be obtained by introducing a very high degree of tolerance into the process. This can be achieved in a number of ways. One of these is to under-utilize the quality potential of the available flour being used. This was dramatically demonstrated in South African bakeries in the mid-1980s. Potassium bromate was not a permitted additive, the baking industry was under strict government control and most of the bread observed appeared to have been produced from immature, or green doughs. The result was loaf after loaf, looking and eating exactly the same. It was not bread of the highest quality, but it was absolutely consistent. In this case the tolerance of the process to variations in the raw materials and the environment was very wide. With deregulation of the industry and the availability of modern improvers, the general quality of South African white bread has improved dramatically (Young 2007), but it is no longer so consistent because the tolerance of the process has been reduced.

This balance between process tolerance and optimism of dough development is an interesting one. Ultimately it is the consumer and the market place which dictates what bread quality is acceptable. In many cases, some of which are discussed above, local markets have evolved a particular set of bread characteristics which are considered to be the standard and the introduction of bread which is 'improved' and therefore 'different' may not be readily accepted by consumers. However, one of the key drivers of sales in the market place is the sensory shelf-life of products, especially with respect to crumb softness. As has been noted several times in the chapters throughout this book, there is a strong link between dough development and crumb softness. This often means that when under-developed doughs are used to provide process tolerance that crumb softness may be compromised. The addition of crumb softening agents via improvers may address the issue to some degree but they seldom deliver all of the organoleptic qualities that come with optimized gluten development by mixing.

Water

After flour, the next most important ingredient used in breadmaking is water (Cauvain and Young 2008). The impact of water addition on quality is often overlooked. Seibel (1994), in recognizing the importance of freshness in determining consumer acceptance, claims that ‘higher water additions are being used worldwide, resulting in more sensitive doughs needing special equipment’. This was probably only true for pan breads at that time. In order to maintain their shape, many varieties of bread baked on the sole of the oven or in shallow pans need to be made from firmer doughs than those used for pan bread. This will be a contributing factor to the way in which the keeping qualities of these breads diminish rapidly after the bread leaves the oven. A baker accustomed to making European, hearth-type breads will have difficulty in adjusting to the need to increase the water to the extent necessary to produce longer-keeping pan bread.

English bakers have gained a reputation in other parts of the world for ‘overdoing’ the water addition. The sensitivity to dough damage during processing can in part be related to dough water levels but it is also true that under-development and inappropriate equipment design and operation contribute to the problems encountered in processing soft dough. If dough development is optimized then it is perfectly possible to use higher recipe water levels and in doing so this can lead to a reduction in dough damage. In countries where bread weight has been determined by measuring the dry solids content, water additions tend to be limited. This had the opposite effect and bread keeping quality is adversely affected. A change in legislation in some Australian states in the early 1990s highlighted the need to take into account the local legislative component of the environment when considering factors which influence the breadmaking process. In this case, bread weight legislation changed from a dry solids basis to net weight. This had a significant effect on bakers’ expectations of flour water absorption, to which some mills had difficulty in adjusting. Also, water absorption became and remains much more of a significant factor in determining the acceptability of new wheat varieties for the Australian domestic market and some of the emerging bread markets, like Indonesia.

Yeast

Modern bread yeasts are now available in most countries of the world. Compressed yeast and cream yeast are by far the most commonly used in plant bakeries. Active dry and vacuum-packed instant yeasts are now readily available and are often used in those areas where distribution is difficult and storage facilities are inadequate to maintain the viability of live yeast. While most bakers will use yeast from a specialist supplied to ensure consistency of gas production, very traditional bread production systems are based on the production of mother and starter doughs. The action of lactic acid bacteria produces both organic acids and carbon dioxide gas and this fermentation alone may be sufficient for the manufacture of some bread types. However, in other variations, baker’s yeast may be used for a pre-ferment or as an addition at the final dough making stage. Once almost exclusively the province of the artisan baker, the use of pre-fermentation systems has become more industrialised and is found being used in many larger bakeries.

Salt

In the past the use of salt in bread is mainly influenced by consumer preference and varies from the extremes of zero for unleavened chapatti to a reported 3 % for a popular Hungarian product (Lasztity 1995). Most Western-type pan bread has usually been made from dough containing around 2 % salt by weight of flour. However, concerns over the negative impact of high sodium levels in the diet has begun to have a significant impact on salt levels in bread. As discussed earlier (Chap. 3) foremost in this area has been the UK where government pressure on the baking industry from the Foods Standard Agency and the Department of Health has increased to lower salt levels in a range of baked products and other processed foods. This is because of the potential links between salt levels in the diet and high blood pressure and other possible medical conditions. In the UK this pressure has resulted in a gradual reduction in salt levels in bread with the promise of more to come. Similar pressures and in some cases legislation have been applied for salt reduction elsewhere in the baking world, though most countries have yet to set targets as low as those considered in the UK. For the baker taking salt out of the dough is not necessarily a simple matter since sodium chloride makes contributions to dough development and fermentation control. A gradual reduction in salt level is probably the best way forward as consumers soon recognise changes in bread flavour following significant reductions in recipe salt level. The move to lower salt levels in bread needs to be handled with care in the case the positive health benefits of consuming bread, such as higher fibre consumption (Hartikainen and Katina 2012) are negated by an overall reduction in *per capita* bread consumption.

Other Improvers

The use of dried vital wheat gluten, fats, soya flours, emulsifiers, malt flours and enzyme-active preparations varies greatly from country to country and from one type of bread to another. The desire to maintain product quality often determines the type of improver required and the extent to which it is used. Also, variations in flour quality, environmental conditions and equipment idiosyncrasies have an influence. For instance, one would not expect to find a widespread use of malt flour in northern Europe where wheats with low Falling Numbers are common (Salvaara and Fjell 1995). This is in contrast to the wheat in many Australian states which commonly have Falling Numbers in excess of 400 and malt flour is often used as a base in improver mixtures. In some instances legislative control determines the level to which various additives can be used in bread; for example, in Australia for many years there were legislative limits to many commonly used emulsifiers. In New Zealand there were no constraints for emulsifiers and bakers there have tended to use higher levels than their Australian counterparts. The result is that the crumb characteristics of New Zealand white pan bread tended to be finer, but less resilient, than that found in most Australian bread. Even consumer attitudes can play a role in determining which improvers will be used and at what level. These attitudes may not just be based on flavour or texture consideration but also include concerns of the presence of genetically modified materials.

Dividing

Following mixing and development of the dough, either entirely in the mixer, for no-time doughs, CBP and continuous mixers, or by fermentation, the next stage in the breadmaking process usually comprises dividing the original bulk dough into the sized pieces needed for further processing and baking. This is just as true for the unsophisticated domestic production of chapatti as it is for the mechanical production of Western-style packaged breads (Sidhu 1995). The bulk dough must be divided into pieces of specified weight to produce a loaf of the nominated net weight without damaging the bubble structure of the dough. This double objective often requires a compromise between achieving accuracy of weight and minimal damage to the dough. This compromise is not often fully appreciated by some machinery manufacturers whose experience is frequently limited to one type of process. In some parts of the world, for example Australia and New Zealand, bakers have had difficulty in convincing manufacturers of extrusion-type dividers that while that type of divider admirably meets the first part of the objective very well, it can cause severe damage to the delicate structure of CBP doughs. This damage can, to some extent, be reduced by the use of stronger flours, or by the addition of dried gluten. However, this negates any cost advantage of improved accuracy. For this reason most bakeries in such countries still prefer to use suction dividers.

Resting

This is now the term commonly used to describe the stage in bread production between moulding and dividing. Sidhu (1995) used it in his flow charts describing the production of unleavened bread. This is in contrast with the Western term, intermediate or first proof, which describes the stage of breadmaking where the dough is allowed to relax between moulding stages. Of course, intermediate proof, implying as it does yeast activity, would be quite inappropriate when referring to unleavened bread. The term ‘intermediate’ refers to the proofing stage following bulk fermentation (first proof) but before final proof prior to baking. Where no bulk fermentation takes place, e.g. in no-time doughs, first proof would be a more accurate term. However, the term ‘intermediate proof’ is firmly fixed in bakery terminology around the world. The purpose of intermediate proof is to produce a piece of dough which is sufficiently soft, extensible and relaxed to allow optimum performance in the moulding stage. It also provides time for dough pieces to become properly mature. However, recent developments have seen significant reductions in the length of this period to such an extent that it is hard to argue that there is any significant gas production by the yeast. The changes in dough rheology that might have occurred when the dough rests have now largely been achieved by changes in the mixing stage.

Apart from equipment variations, the main difference found in this stage of breadmaking is that of time. This can vary from almost zero in the case of some continuous bread production methods to as much as 2 h used by some methods of producing continental types of bread. In the latter case the intermediate proof partially replaces bulk fermentation, but it also serves to create the very open texture preferred by the consumers of this bread. In this case it is not just relaxation which takes place but it also allows the considerable yeast activity necessary to produce the carbon dioxide required to create the preferred texture characteristics. This dough structure needs to be maintained during the next stage.

Moulding

The purpose of moulding is to create a dough piece of the right shape while at the same time producing a dough structure which will result in the best possible texture in both the internal crumb and external crust of the final product. In the example of continental bread types referred to in the previous section, this means very gentle moulding so as not to damage the texture formed during intermediate proof. This is also true for the correct moulding of CBP doughs even though the gas bubble populations in such doughs are very different. In this process the required dough structure is formed at the mixing stage and should be protected right through to the actual baking.

Doerry (1995) claims that the purpose of the first stage of moulding, sheeting, is to expel the excess gas from the dough pieces, thus ‘degassing’ it. While this may be an appropriate description for what happens in some North American bakeries, there is no explanation as to how this can be achieved without damaging the structure of the dough. It certainly does not apply to CBP doughs where, throughout the process, it is essential to maintain the structure of the dough created during mixing. Indeed the gas levels in some CBP doughs are so low (Cauvain and Young 2006) that it is difficult to see how much de-gassing can occur. In part the rationale for de-gassing dough by sheeting is based on the manufacture of doughs using bulk-fermentation or floor time. It is only in the recent years that the need for de-gassing of dough pieces has been seriously challenged and equipment design has changed to become more ‘dough friendly’ and ‘stress-free’.

Panning and Pans

It is a matter for discussion as to whether the pans used by bakers in different parts of the world determine or reflect many of the characteristics of the final product. By the mid-1980s bakers in the UK, Australia and New Zealand introduced a new baking pan which significantly changed the size and shape of what had been the traditional loaf shape in that country. From being a relatively long narrow shape the loaf became rather shorter, broader and higher. The specific volume was increased by about 25 % from approximately 4.0 to 5 ml/g or somewhat higher. This type of bread product, which was much softer, met with immediate consumer acceptance and is now an accepted shape for packaged bread. In response to consumer demands for even softer bread, the specific volume is now approximately 6.0 ml/g.

It is interesting to note that in doing this, New Zealand bakers were able to increase the oven throughput and thus obtain an economic benefit. In contrast, as a result of a different oven tray and pan configuration, Australian bakers, in doing the same, were faced with a reduced throughput but, because of the consumer acceptance experienced in New Zealand, made the change regardless. The consumer acceptance in Australia has been similar to that in New Zealand. It is also relevant to note that Nagao (1995) reports that in Japan 'the introduction of a new white pan bread with a softer crumb than normal was welcomed by consumers and resulted in the recovery of total white bread consumption.' In the UK breads have a higher specific volume, i.e. they are less dense than the 'standard' product. The premium product attracts a higher price. Such moves demonstrate the advisability, indeed necessity, of producing bread which meets consumer requirements. The use of pans allows bread dough to be softer and to flow more than when the dough piece is required to be self-supporting, and hence is a prerequisite for the production of 'soft' bread with a thin crust.

Final Proof

With the possible exception of single-layer flat bread, the doughs for leavened bread are subjected to a period of raising before being baked. The purpose of this is to allow the moulded dough piece to relax and expand to produce an aerated piece of dough which, when baked, will be of the required shape and volume. The warm, humid conditions which are necessary for this process to occur are well understood and practised by bakers everywhere. There is perhaps a lesser understanding of the time needed for this to produce the required results. Failure to allow enough time can result in the dough piece being unable to relax sufficiently even though it has risen the required amount. This in turn can result in misshapen loaves and has been evidenced in both Australia and New Zealand when process and raw material changes have occurred. This is another example of the challenges which are faced when transferring technology from one environment to another. An exception to the humid proof conditions is that of double-layered flat breads. During the final proof of these products the surface dries out, resulting in the formation of a skin which assists in the formation of the double layer during baking (Qarooni 1995).

Baking

Baking is the final step in the making of a loaf of bread, during which heat is applied causing the rapid expansion of gas in the dough, water to be driven off, the gelatinization of starch and the coagulation of proteins. These reactions, together with the formation of a crust, transform an unpalatable dough piece into a (light) porous palatable loaf of bread which is nice to eat. It is the last few words which distinguish the different types of bread. Not only do the types of oven differ significantly, but baking times can vary from as low as 18–20 s for Arabic bread (Qarooni 1995) to over 1 h for heavy, dense rye breads of Eastern Europe. The range of oven temperatures is equally wide; between 150 and 650 °C. These extremes may seem way out to bakers used to baking Western-type breads at around 200 °C. Each situation can be explained by the fundamental principles of heat transfer and a knowledge of the gelatinization properties of moist starch. With the very thin Arabic breads the intense heat from the clay oven very quickly gelatinizes the starch and coagulates the proteins in the centre with minimal crust formation. The thicker the bread, the longer this process takes. In double-layered Arabic bread the rapid generation of steam and expansion of carbon dioxide during the first stage of baking forces the separation of the top and bottom crusts and creates the characteristic pocket.

This is the same process which takes place in Western-style pan breads, but the lower temperature, slower heat transfer, and different volume and shape of dough produce a different result. Attempts to vary the process for making Arabic bread by retarding dough results in a product which could be acceptable to Western consumers but may not find favour with those used to the traditional product (Inoue 1995).

Bakers with an understanding of heat transfer principles will also recognize that differing oven conditions found in bakeries in Western countries are necessary because of different characteristics of the end products. In the UK, New Zealand and Australia the move to bread of higher specific volume has also resulted in reduced baking times. The heat transfer in the less dense dough piece means that the internal temperature can reach 94–96 °C, sooner than was previously the case.

Cooling

In the markets where sliced and packaged bread dominate, bakers are required to give close attention to the conditions under which bread is cooled before it is sliced and packed. During this stage of bread production it is necessary to reduce the temperature of the bread to a level at which it can be sliced and packed without damage to the loaf either during slicing and packing, or later due to excessive mould growth. In markets where there are no restrictions on the moisture content of bread, the extent of moisture loss and hence weight loss during cooling needs to be taken into account. This moisture loss can be significant and should be avoided. Not only will excessive moisture loss adversely affect the cost of manufacture but it will also accelerate the staling process (see Chap. 10).

The design of a bread cooler which may be suitable for the climatic conditions experienced in the UK would be quite inadequate to deal with the humid conditions in a country like Singapore or the extremely dry conditions of, say, Perth in Australia. Each of these situations requires its own particular design criteria to enable bread to be cooled under conditions which will produce optimum results. Like every other stage of the breadmaking process, the correct balance of all the factors involved needs to be achieved. Machinery manufacturers and bakers alike need to adopt an approach based on sound scientific principles when designing and specifying equipment to be used in different situations. Using first principles, process requirements need to be matched with equipment design to produce the required results under the conditions where the operation will take place.

Slicing and Packing

The final stage in the production of modern Western bread is also subject to variations from country to country. Depending on the nature of the product and consumer preference, the thickness of the slice can vary, as can the package. For instance, the thickness of sandwich bread in New Zealand is approximately 10 mm while in Australia for a similar type of loaf it is 13 mm, and in the UK it is typically 15 mm. The type of equipment will also differ considerably and the different type of bread found in different Western countries also dictates the type of slicing machine used. This difference has been demonstrated in New Zealand. As the specific volume of the bread increased, bakers had to change from using the reciprocating slicers common in the UK to the band slicers usually found in North American bakeries. The band slicers handle the softer, higher volume bread much better than the reciprocating slicers. At the other end of the scale it is necessary to employ special spinning disc slicers to cut very heavy, dense rye bread.

Packaging

The function of bread packaging for breads can be described as:

- To maintain product quality by reducing crumb drying, minimizing the risk of contamination.
- To contain the slices and crusts together in a single unit for handling purposes.
- To present an appealing and informative package to the consumer.

The most common material now used is a low-density polyethylene, usually in the form of bags. This product provides a good barrier to water vapour, thus inhibiting drying, is easy to handle, and provides a clear background through which the consumer can see the product being purchased.

Many attempts have been made to package French-style country breads so that the crustiness can be maintained. These have met with some success, by employing perforated film to prevent moisture equilibrium being achieved between the crust and crumb. However, since some moisture loss is inevitable through the perforations there is a gradual overall loss of moisture from the product. Since a moisture gradient is to be maintained to preserve crustiness it is inevitable that the crumb will become firmer as its moisture content falls with increased storage time.

With the increasing emphasis on consumer information in many countries, the bread package, like other food packaging, is becoming more and more informative. The responsibility of bakers to ensure that the information they provide is accurate and informative has also increased. Consumer laws regarding misrepresentation and false information mean that not only must the original source of the information be correct, but that products within the package must be consistently made to standard recipes. This all requires an extremely high level of quality assurance and traceability.

Bread and Sandwich Making

Bread and other fermented products have always played a significant role in the development of the convenience food and snack market. In the past the use of sliced bread to prepare sandwiches was essentially confined to the home. Gradually as the advantages of having an edible ‘package’ were realised bread-based convenience products proliferated. Today bread finds use in the preparation of hamburgers, sub-rolls, filled baguette, filled croissant and flour tortilla wraps. However, it is perhaps the re-discovery of the sandwich based on two slices of bread from a lidded loaf that best show both the versatility and utility of bread. In the UK it has been re-born as the classic ‘meal on the move’ and the sandwich making industry has grown to be worth an estimated GBP five billion. It is based on large-scale production of both bread and the assembly of the sandwich components in specialist units and sells in large retailers (see Fig. 8.1), gas stations, food halls, coffee shops, airports and rail stations (Cauvain and Young 2010).

A wide variety of bread types are used in the manufacture of the sandwich with the standard white loaf being relegated to a supporting role in sales. In part, this arises because the sandwiches must be held at refrigerated temperatures (5–8 °C) at the point of sale for food safety reasons. This does not present the bread at its best since bread stales fastest at around 5 °C (see Chap. 10) and if (as is often the case) the sandwich is consumed relatively cold the bread ‘lacks flavour’. Additions of fibres, cracked grains, malted products and even oatmeal all restore some the flavour of the bread product. It is interesting to consider that the bread component of a sandwich is still required to have flavour despite the fact that the fillings are commonly more flavourful than the bread. A further contributing factor to the loss of bread flavour in the UK has been the progressive reduction in recipe salt levels discussed above.

Fig. 8.1 Sandwich display

The development of the UK sandwich market has significantly impacted on the bread baking industry. The sandwich maker sees the properties of every slice of bread during the sandwich assembly process and effectively quality controls every slice. The triangular pack has become the industry standard and this in turn has placed exacting standards on the bread baker. Tolerances to variations to lidded loaf height are small; too large a slice area and the bread triangle will not fit the pack, too small and the sandwich moves around in the pack and is likely to lose its filling. The sides of the sandwich loaf must also be straight and without indents. Figure 8.2 illustrates the measurement of side wall concavity with the C-Cell image analysis system and in this respect is similar to Fig. 1.8. However, in the case of sandwich bread any dips in the top crust of the loaf are equally important are avoidance of such features is equally important in sandwich making. Objective measurements of the physical dimensions of the loaf may well be incorporated into bread specification by the end-user. Even the internal features are carefully scrutinised by the sandwich maker. Large holes (e.g. Fig. 8.3) are unacceptable since the filling tends to fall out and makes a mess in the pack and a coarse cell structure can lead to the sandwich assembler using too much butter or margarine spread.

The exacting standards of the sandwich maker are passed back to the bakers who must now ensure better control of raw materials, recipe and process in order to meet the requirements of their customers. It is no longer a case of worrying about whole loaves meeting specifications but of each slice has to be ‘right first time’. Such demands have led to the emergence of bakeries dedicated to making little else

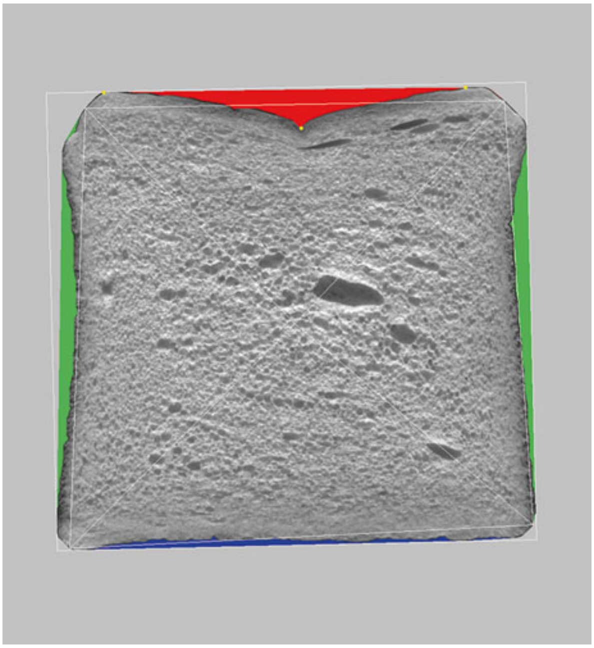

Fig. 8.2 Measurement of crust concavity of sandwich bread by C-Cell (Courtesy *BakeTran*)

Fig. 8.3 Unwanted holes in the crumb of sandwich breads (Courtesy *BakeTran*)

other than bread for sandwich making, not just a few loaves but often 12,000 units an hour, 24 h a day for 6–7 days a week. To meet the exacting standards true ‘partnerships’ have been formed with bakers, ingredient suppliers and sandwich assemblers all working to a common goal—to make the humble sandwiches, but lots of them.

The sliced bread sandwich has not been confined to the UK with British bread for sandwich making being exported far and wide, including daily deliveries to the south of France and weekly frozen bread supplies to Japan. Production of the bread and assembly of the sandwich is also spreading with plants operating in France, Spain, Greece, Romania and Turkey. Another example of the truly universal nature of bread and the consumer-led desire for new products.

Crustless Breads

The contribution of the crust on bread and fermented products to flavour has been discussed in earlier chapters (see Chaps. 1 and 5) but a significant part of the consumer base—children—apparently do not like the texture or flavour that comes with the crust. This seems to be especially true for the preparation of sandwiches. It is somewhat ironic to watch some consumers removing the crust and throwing it away (or feeding it to the birds) while others will tear out the crumb of baguette and simply consume the crust.

The marketing opportunity for crustless breads has often been met in the USA, Mexico, Spain, Indonesia and elsewhere by removing the crusts from standard loaves baked in pans. This may seem a simple enough product to make but it is not without its technical challenges. In particular the dimension of the slices and their weights must meet the appropriate quality and legislative criteria, and this requires careful control of the density distribution in the slice cross-section. Too much centre crumb expansion may result in the slice weight being too low while the weight of crust will increase. Even though the bread crust may be used for other products (e.g. food coatings) the price differential may well dictate that bread quality should be closely focussed on the crumb.

More recent developments have produced a genuine crustless or sometimes called an ‘invisible’ crust loaf (Fig. 8.4). The product has thin but colourless crust

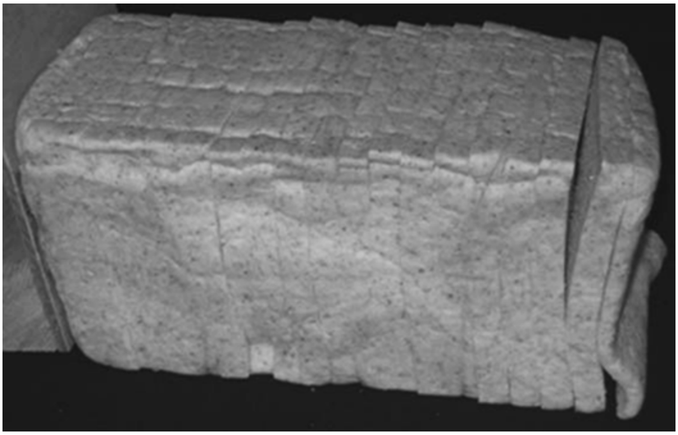

Fig. 8.4 Invisible crust loaf made from a mixture of white and wholemeal flours

with an appearance and texture similar to that of Chinese steam buns. The outside of the product is soft to the touch and the crumb cell structure resembles ‘conventional’ bread. Different baking technologies are used to make such products (Anon 2011) including microwave baking (Anon 2009) and vacuum cooling. Once again such developments show the ingenuity of bakers and the diversity of products that are classified as bread.

The International Market

Western style bread is now made in many Asian, Middle Eastern and African countries. Arab-style pocket bread is made in many Western countries. French-style crusty bread is made throughout the world. Canadian, American, Australian, European, Indian and former Soviet states export wheat all around the world, depending on the availability of crop surpluses and market demands. The result of this position is that many traditional breadmaking methods have been modified and traditional products have had their characteristics altered as they have been made with non-traditional flours and equipment. Tradespeople in some countries have had to be extremely versatile in adapting to an inconsistent supply of flour made from wheat which has been imported, stored and distributed with little or no regard for its breadmaking properties (Sidhu 1995). Consumers who have not been exposed to an authentic loaf, made within its homeland, may become accustomed to a somewhat different product, once again illustrating the diversity of wheat based products.

To overcome some of these problems, much work has been done in laboratories in an effort to characterize the flour, and hence wheat, requirements for products made from wheat grown in one country and exported to another. For example, the former Australian Bread Research Institute defined appropriate flour requirements for products such as Arab bread (Quail 1996) and Chinese steam bread to be made from Australian wheat. Similarly the American Institute of Baking and the Canadian Grain Commission (Kilborn and Tipples 1981) have studied the breadmaking processes used in countries importing wheat from their respective countries.

In many cases the challenge still remaining is for that knowledge to be transferred from the original publications to practical use. This challenge applies not only from country to country but within individual countries. The results of what is probably the most successful transfer of baking knowledge on an international scale can be seen in the ubiquitous Big Mac. The McDonalds hamburger chain has been successful in facilitating the worldwide adaptation of the baking process and raw materials to produce a product which is largely indistinguishable from country to country. This is an excellent example of the requirements of the end product dictating not only the control of the manufacturing process but also the specifications of all the raw materials. This has in some cases (e.g. New Zealand) resulted in a special wheat being grown. This has only been achieved by a thorough and complete understanding of the principles involved.

One aspect of this, which applies throughout the world is the need to distinguish between craft skills and those required by operators of large plant bakeries.

Most practical courses for bakers place a heavy emphasis on the former to the detriment of those whose skills should be in operating what should be the rigidly controlled process of automated bread manufacture. There are some examples of steps being taken towards achieving this. In Australia the Plant Baking Industry, in conjunction with the Australian National Food Industry Training Council developed a 'National Certificate in Food Processing—Plant Baking'. It was anticipated that this certificate would eventually replace traditional apprenticeships as far as most plant bakery operations are concerned. It is also interesting to note the fact that this project was being conducted under the auspices of the Cooperative Research Centre for Quality Wheat Products, a joint industry and government research initiative. Such an integration of research and training follows that adopted by organizations such as the American Institute of Baking, the Australian Bread Research Institute and the New Zealand Crop and Food Research Institute Ltd. This approach facilitates the uptake of research findings by industry and ensures that the most up-to-date knowledge is included in training programmes. There are also a wide range of customized bakery training courses which can be readily identified by searching the World Wide Web.

As a result of the research being carried out in cereal food laboratories around the world, the molecular basis of the baking process is gradually becoming clearer (Cauvain 2012). With this level of understanding it is only a matter of time before a significant technological breakthrough occurs. As the basic building block in the process is dough formation, this breakthrough is likely to occur in that area of cereal science. Already the possibilities for lower energy requirements for dough development are being mentioned (Larsen 1996; Millar and Tucher 2012), and these are likely to impact breadmaking methods with benefits accruing to the whole world of baking.

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Chapter 9
Speciality Fermented Goods

Introduction

The manufacture of fermented products is not focussed exclusively on bread, though larger sized bread products do constitute the major part on production and sales in many parts of the world. With the availability of a wider range of bread products increasing through globalisation and travel the manufacture of speciality fermented products is increasingly becoming associated with main stream baking. The term 'speciality fermented goods' is rather difficult to define but typically encompasses products which are neither bread nor cake. Mainly they are small sized bakery products without a legal definition but covered in EU legislation by the term 'fine bakery wares'. They may range from very lean, crusty products to goods containing high levels of fat and sugar, and possibly fruit and spice (e.g. hot cross buns) and include laminated croissants and Danish. The key common factor is that they all require an appreciable level of gluten development in the dough though not necessarily as much as would be required for bread (Cauvain and Young 2006). In this chapter concentration has been placed on four major areas of speciality fermented goods, namely hamburger buns (Fig. 9.1), part-baked bread, croissants and Danish pastry production, with some brief comments on hot-plate products.

Hamburger Bun

Production Rates

Hamburger bun plants come in a range of sizes with examples having outputs of up to 66,240 buns per line per hour. This example comes from an eight-lane AMF Extrusion Bun Divider operating at 138 cuts/min, i.e. $8 \times 138 \times 60 = 66{,}240$. For a week's production of say 160 h (plus 8 h cleaning and maintenance) the output of each line would be $66{,}240 \times 160 = 10{,}590{,}400$ buns. European lines of this type

S. Cauvain, *Technology of Breadmaking*,
DOI 10.1007/978-3-319-14687-4_9

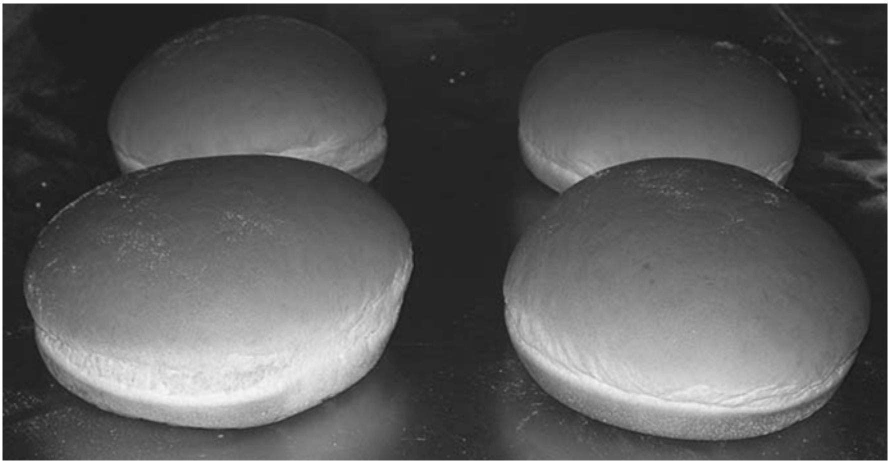

Fig. 9.1 Hamburger buns (courtesy *BakeTran*)

are said to be operating at a maximum of 125 cuts/min. In the USA also commercial speeds at 125 cuts/min are reported (Steward 1990; LeCrone 1994), which gives an output of 1000 buns/min on an eight-lane plant. Even at this slightly reduced rate which equates to a weekly output of $(8 \times 125 \times 60) \times 160 = 9{,}600{,}000$ buns per line, the output is substantial.

Formulation

Table 9.1 compares typical formulae for white pan bread and hamburger buns. Two major differences can be identified; higher levels of fat/oil are used in buns compared to bread and sugar is added to hamburger buns. The reduced water in the hamburger bun formulation compensates for softening of the dough caused by the addition of the higher levels of fat and sugar. Without this reduction, doughs would not process through a plant. The flour for high-volume production of hamburger buns is required to be strong and relatively high in functional protein, to carry the high levels of fat and sugar. Readers interested in microwaveable, hamburger bun formulations based on high fat and high fibre/water ratios are referred to Neufeld (1991).

Liquid Brews and Fermentation

Before the main doughmaking it is common to include some pre-fermentation. Water brews are one option in which most of the yeast, some of the salt and sugar are mixed and fermented with a brew buffer for 60–90 min. Water brews based on 3.5–4.5 % sugar solids and 3.0 % yeast (based on flour weight) are used to develop

Table 9.1 Comparison of a white sliced loaf recipe and one for hamburger buns

Ingredient	White pan bread	White hamburger buns
Flour	100.0	100.0
Salt	1.8[a]	1.8
Water (approximate)	60.0	55.0
Yeast (compressed)	2.5	3.0
Fat	1.0[b]	3–5 (fat/oil)
Sugar	0–20[c]	5–10
Improver	1.0	1.0

It is difficult to give exact protein levels for a flour and whilst they are important, low ash figures and/or low Grade Colour Figures should also be taken into account

[a] An 'average' figure to take into account variations around the world

[b] May be zero in European breads or an emulsifier

[c] Varies from 0 in the UK and many other parts of Europe to around 20 % in India and Indonesia

the necessary amounts of acid to produce good buns (Sutherland 1989). Other methods involve fermenting part of the flour, in the form of a sponge. A traditional sponge takes a proportion of the flour, yeast and salt, and a tight sponge is made with water which is allowed to ferment at specified temperatures. After fermentation of the sponge the balance of the ingredients in the recipe are added and mixing follows to form the dough.

A flour brew (sometimes referred to as a liquid sponge) is a variation of the traditional sponge in which more water is added, usually just a little more water than flour. A slacker and pumpable, sponge is produced. Traditional monitoring of brew development during fermentation is by the measurement of pH and determination of total titratable acidity or TTA. [TTA is a term used to describe the amount of acid in a substance and is the number of millilitres of 0.1 N NaOH needed to raise the pH of 20 g of brew to a value of 6.6 (Sutherland 1989).] In the UK these values are difficult to achieve because of the addition to all white flour sold for baking of 235–390 mg (per 100 g of flour) of calcium carbonate which buffers the brew acidity. Salt can also be used as by effectively retarding yeast activity (Sutherland 1989) and affecting the subsequent formation of organic acids. Dubois (1984) discussed the effect of salt in the brew of a liquid ferment. After a 1–3 h fermentation period the flour brew was degassed, filtered and cooled down to between 6 and 9 °C (41–48.2 °F) by passing it through a heat exchanger to arrest any further fermentation. The cooled brew can then be stored in bulk, in a water-jacketed reservoir or holding tanks, ready for addition to each mix. Sutherland (1989) gives the pH and TTA values shown in Table 9.2. In an earlier article Sutherland (1976) gave further values for ferments and doughs from flour brews, described in Table 9.3. Further information on the changes taking place in brew systems are given by Sutherland (1974), Kulp (1983) and Doerry (1985). An outline of brew equipment is given by Matz (1992).

Correct sanitation procedures should be followed between brews, i.e. water rinsing between brews, and complete system clean-in-place (CIP) must occur at regular periodic intervals, i.e. at least once a week. Prior to the start of a mix, brew is pumped into a liquid batching tank, weighed via load cells and dropped into the mixer. The normal

Table 9.2 Values of pH and TTA for various brews (Sutherland 1989)

	pH	TTA (ml)
90 min water brew	4.2	10–12
2 h, 50 % flour brew	4.95	6.2
3.5 h, 66 % flour sponge	5.05	4.7

Table 9.3 pH and TTA values for ferments and doughs from flour brews (Sutherland 1976)

Flour (%)	pH	TTA (ml)
0	4.2–4.3	12–13
10	4.3–4.4	11.75–12.75
20	4.4–4.5	11–12
30	4.5–4.6	10.5–11.25
40	4.6–4.7	9.5–10.5
50	4.7–4.75	8.5–10
Dough–developer	5.1–5.15	4–4.5
Dough–oven	4.9–4.95	5–5.5
Baked bread	5.1–5.2	3.8–4.2

flour level in liquid brews is commonly between 40 and 50 % of the total. Watkins (1991) described the advantages of liquid ferment systems which have the capacity to handle in excess of 70 % of the flour in the brew, ‘the continuous liquid ferment mixer was developed to improve the mixing action, eliminate mixing damage and gluten separation, and to facilitate the incorporation of higher flour levels’. The advantages to the product are considered to be a softer loaf, cleaner cut, better keeping quality, improved flavour and aroma, a more resilient crumb and an improved sheen. Charbonneau et al. (1978) described bun manufacture with a 65 % liquid ferment sponge system.

Many advantages are claimed for a pre-fermentation of part of the flour. One of the practical advantages of using a liquid flour brew is improved pan flow (i.e. the ability of dough pieces to flow and fill the base of the pan indent), but bulk flour brew held in the water-jacketed reservoir or holding vessel becomes a mixture of batches of brew, which is excellent for long, continuous production runs of similar products and also gives consistency. However, major trials should only be undertaken after the holding vessel has been emptied and cleaned of old flour brew. After cleaning, the holding vessel will be filled with new brew containing the result of a major trial. Minor trials on a day-to-day basis are restricted to those which can be carried out on the ingredients that are added at the mixer. When traditional sponges are used for pre-fermentation, an individual sponge is made for each mix. The traditional sponge system allows for both major and minor trials with each batch.

Mixing

At a scaling weight of 50 g the dough requirements of some plants may be up to 3310 kg (66,240×0.05 kg) per hour; at 85 g the hourly dough requirement will be 5630 kg. Horizontal bar mixers with mixing times of the order of 7–10 min are traditionally used to produce the dough. The machine mixing capacity is considerable and can be up to 1300 kg per batch. Substantial refrigeration on the sides of horizontal bar mixers help in producing the required ex-mixer dough temperature of approximately 26–27 °C (78–81 °F). The exact ex-mixer temperature will be plant specific and will depend on the pipe length and the heat generated during dough transfer and handling on a plant. High-speed mixers suitable for producing dough using the CBP with energy meters to control the mixing energy and time (see Chap. 4), are used in some hamburger plants. During a standard CBP pan bread mix to 11 W h/kg of dough, a temperature increase of the order of 15 °C temperature rise is generated in the dough. The control of dough temperatures during warmer months of the year becomes very important. Thompson (1983) stated that doughs mixed on high-speed mixers using normal-strength American wheat flours require somewhat longer mixing times (brought about by a higher energy requirement per kilogram of dough) than those common to the softer wheat flours of the UK. This will lead to a greater increase in dough temperature during mixing. The addition of refrigerated liquid flour brew to a high-speed mixer will contribute towards controlling dough temperatures (Thompson 1983). When a 40 % flour brew is used nearly half the weight of each mix is refrigerated flour brew. The use of the pressure/vacuum, CBP, high-speed mixer (described in Chap. 4) may have benefits in the future of hamburger bun manufacture, especially when producing them in the absence of potassium bromate.

Dough Transfer

After mixing, the dough is emptied into a dough pump. A pair of augers gradually move the dough through an outlet at the base of the dough pump or hopper. The dough can then be moved onto transfer conveyors or through a pipe for delivery to the divider. At maximum output of 50 g rolls, an eight-lane extrusion divider will use 0.05 × 138 × 8 = 55.2 kg dough/min. If a large mixer is used to produce, say, 1300 kg of dough, it will then take 1300/55.2 = 23.56 min before all the dough is divided. During this time some fermentation will occur and chemical reactions will continue; the action of the augers in the dough pump is said to homogenize and degas the dough during transport. This supplies a dough of a more uniform density to the divider, from the beginning to the end of each dough.

Do-Flow Unit

The Do-flow unit is sited above the divider and is a kneader that degasses the dough before it enters the divider. The Do-flow unit is said to allow precise control of product grain structure. Dough from the dough pump/hopper is delivered into the

Do-flow unit onto a helical feed screw which controls the rate of dough delivery onto the developer paddle. The developer paddle further develops the de-gassed dough, which is extruded as an even curtain of dough into the divider hopper. The Do-flow unit supplies the divider with a dough of uniform density from the beginning to the end of each batch, which enhances scaling delivery. The speeds of the feed screw and the developer paddle are adjustable.

Dividing

The bun and roll make-up systems of AMF offer two types of dividers, the Model K divider head and the Extrusion Bun divider (similar types of Do-flow units, dividers and first provers are also made by other manufacturers, e.g. Dawson and Cummins Eagle, Inc.). The Model K divider consists of a stainless steel rotating drum which has two rows (four or six across) of cut-out cylinders. The rows are on opposite sides of the drum. Dough enters the divider hopper and is drawn by vacuum into one of the rows of cylinders. As the drum rotates, a knife cuts off the dough. In the down position a piston is activated and forces the dough to the edge of the cylinder. A wire then releases the dough from the edge of the piston bore and the dough pieces drop onto the bed of the final moulder. The Model K divider can operate at up to 100 cuts or strokes per minute. The Model K uses divider oil to prevent dough from sticking.

With the Extrusion bun divider, dough is drawn into a vacuum chamber containing rotary screw augers. It is fed into a metering pump which then goes to manifolds containing adjustable valves on each outlet. Altering the valves changes the weight of dough from each outlet port. The dough is extruded from four, six or eight extrusion ports where a knife or blade cuts off or guillotines the extruded dough into equal pieces onto the bed of the moulder. The device used to cut off the dough piece must operate at extremely accurate, highly repeatable frequencies in order to divide the extruding product in equal portions (Steward 1990). The speed range of this type of divider is from 40 to 138 cuts/min with an accuracy of ±1 %. The operation is such that no divider oil is required.

AMF Pan-O-Mat

The Pan-O-Mat rounds, first proves, forms and pans dough pieces. From the divider the dough pieces drop onto the final moulder which consists of an endless belt. Across the moulder belt four, six or eight rounder bars are accurately placed. The dough pieces travel down special concave rounder bars, which are designed to round each dough piece into a smooth, surface-sealed ball.

Dough pieces, which originally left the mixer at 26–27 °C (78–81 °F) and have passed through a dough pump, Do-flow unit, and a Model K dividing head, leave the rounder bars at a temperature of approximately 30 °C (86 °F). Steward (1990) considered that with the extrusion type of divider, because no oil is used on the dough or the rounder belt, the dough balls begin to round immediately upon contact with the rounder, which improves indexing gate transfer efficiencies and reduces the number of doubles in the intermediate prover.

From the moulder bars a driven kicker bar transfers the dough pieces onto the zig-zag board. On the zig-zag the dough pieces pass down an incline from the final moulder. A fine dusting of flour falls onto the zig-zag and each dough piece is evenly coated in a thin film of flour. The dough pieces are assembled again in a row and transferred into a tray of prover pockets by a synchronized rotary gate system.

The short first proof period allows the dough pieces to relax sufficiently for the final sheeting and forming. At the end of first proof a row of dough balls are inverted and discharged into what are known as closed clam shell gates. The latter ensure that the dough balls enter (when the clam shells open) the adjustable sheeting rollers at the same time, which allows an even row of sheeted or slightly flattened dough pieces to be transferred into the indented pans (after the sheeting rollers, additional equipment can be fitted, e.g. a finger pressure board, which moulds the dough pieces into a hot dog or finger shape). The pans are fed by conveyor under the sheeting unit and a pan stop and indexer system synchronizes each row of indented pans just under the discharge conveyor.

Flour Recovery and Pan Shaker Units

The tray of buns then passes through a unit which employs targeted jets of compressed air to just lift each row of buns, whilst an extraction unit removes unwanted excess flour from the surface and importantly from the base or heel of each dough piece. An adjustable pan shaker is then employed to ensure that the dough piece is in the centre of each indent. At the start of a run the pans are likely to be cold and will require a higher setting on the pan shaker to centralize each dough piece. Once the pans have been round a plant and through the oven and become warm, the dough piece tends to move more easily in silicone-treated pans, and consequently lower pan shaker settings are required.

Proving

Large-scale high-volume hamburger bun manufacture usually employs a proof and bake system. Baking pans are moved by a track into a conveyorized prover. With this system, pans are supported either by a device in the centre of each tray or by a magnet. A track then transfers the pans into the oven on an endless conveyor. Before entry to the prover the space between each baking pan is monitored. Within the prover the track bends in an oval and gradually travels to the top, crosses over and then down again. Correct spacing of the pans is essential if the edges of the pans are not to collide as the track bends. The prover temperature and relative humidity are adjustable. Typical settings for hamburger buns are of the order of 38 °C (100 °F) and 78 % relative humidity, for a proof time of between 50 and 55 min depending on the weight of the bun. Proving time is altered by changing the speed of the track.

Seed Application

After an appropriate proof time, the track with indented pans full of proved dough pieces leaves the prover. If the buns are to be covered with sesame (Fig. 9.2), other seeds or grits, the pans of proved dough pieces are passed through a water mist to give a fine and even covering of water. Immediately after this, seeds are evenly distributed onto the top surface of the proved buns. Two systems are available for adding seeds. In the first, after water misting the pan activates the vibration of a tray of sesame seeds held at an adjustable height above the pans. The base of the flat hopper of sesame seeds is perforated and the vibration releases seeds onto the top of the tray of buns. The time for which the tray vibrates and the degree of vibration are adjustable. These adjustments will alter the weight of seed applied. The second system uses the pan indents to activate a mandrel or a grooved spindle, housed in the base of a hopper of sesame seeds. As the spindle revolves, seeds are released onto the top surface of each row of dough pieces. Whichever type of seed applicator is used, it is

Fig. 9.2 Hamburger bun coated with sesame seeds (courtesy *BakeTran*)

important that they are positioned correctly and level and that the correct settings are made appropriate to the seed and product to ensure an even coating on the top surface of the buns. The surface of finger rolls can be partially slit down the centreline with a water splitter. The pressure of the water in the jets is adjusted to alter the depth of each cut.

Baking

The pans of fully proved, seeded buns are then transferred onto an oven track, and the spacing or distance between each pan is again monitored to ensure correct spacing for the bends in the conveyorized oven. In a gas oven the pans pass over adjustable ribbon burners. The various layers of track are divided into six controlled temperature zones. In each zone the temperature is adjustable. In addition to the ribbon burners, fans are used to increase hot air circulation, to ensure an even heat distribution. Typical baking temperatures for hamburger buns are of the order of 220 °C (428 °F) for 7.5–9.5 min depending on the weight of the product on the line (Fig. 9.3). Further details on conveyorized proofing and baking systems are given by Wells (1983) and Grogan (1980).

Fig. 9.3 Hamburger buns leaving the oven (courtesy *BakeTran*)

Depanning and Cooling

After baking, the track passes under a depanner unit and compressed air is used to loosen the buns from the tray, while a vacuum unit removes some of the surplus seeds. A belt which is as wide as the tray of buns, made up of special soft depanning cups, is employed to remove the buns from the tray. Through each cup an adjustable vacuum is employed. The cups gently suck the buns off the tray and place them onto a cooler. Typically, a stainless steel spiral cooling conveyor is used. The cooling of buns takes in the order of 20 min, during which they are cooled to 35–38 °C (95–100 °F) before slicing.

From the cooler the buns are aligned into six lanes, and bunches of five rows are then sliced and placed into a pillow pack possibly with a central seal to give 2 × 15 buns in each pack. The date-coded pillow packs are then passed through a metal detector and placed on cleaned trays which may be automatically stacked, ready for dispatch from the production area. For most products, a double layer of buns in pillow packs are added to each tray. The bottom layer should have the same characteristics as the top layer. The bottom layer should not show any signs of compression (wrinkling on the surface typically known as 'crow's feet'). Further details of slicing and packaging are given by LeCrone (1994).

The baking pans are then conveyed back to the Pan-O-Mat via an in-line tray cleaning system. As an aid to keeping these high-volume plants clean, the baking pans are not greased at all but are treated with a non-stick material. Various non-stick pan coatings are available. Typical materials are silicone glazes, rubberized silicone and fluoropolymers (Schneeman 1995; Moss 1987).

Part-Baked Breads

Introduction

Part-baking is a term used to describe a method of bread manufacture which involves two stages of baking, other terms include partially baked, par-bake and brown-and-serve (Pyler 1988) During the first stage, dough pieces are baked just to the point when they are 'set', traditionally without colour formation of the crust (Fig. 9.4). After cooling, packaging and distribution, the uncoloured partially baked dough pieces are given a second bake which forms the crust and final colour (Fig. 9.5). Additionally, the characteristic aroma of baked bread is produced. Typically part-baked products have a small unit size and include French-style breads, rolls, buns, pizza bases and laminated Danish pastries and croissants. Kamel and Stauffer (1993) considered that 'part-baking is most successful with products which have a large surface area in relation to crumb area, such as baguettes, where the heat can penetrate quickly to the crumb centre to set it without setting the crust'. Stoecklein (1995) defined part-baked as 'baking beyond the point of starch gelatinization to some 90–95 % completion in terms of desired crust colour and crispness' which equates to about three-quarters of a standard bake.

Fig. 9.4 Part-baked rolls after the first bake (courtesy *BakeTran*)

Fig. 9.5 Part-baked rolls after the second bake (courtesy *BakeTran*)

The convenience of part-baked breads allows small retail shops to offer hot bread for sale, for example butchers and even mini shopping stores at fuel and railway stations. Brittain (1996) considered that 'Different outlets use bake-off in different ways. Its rise in non-bakery related outlets such as garage forecourts and butchers continues unabated'. Baking off part-baked bread can be a solution for catering establishments wanting to offer customers crusty hot bread and rolls, whatever the demand, throughout their hours of opening. Some hot bread is also enjoyed in the home. Supermarkets and food shops offer for sale part-baked breads for the consumer to purchase and finish in domestic ovens.

Manufacture of Part-Baked Breads

Similar plant operations are used to make both 'traditional' bread and part-baked bread (Cauvain 2014). Some modifications to the formula to increase the stability or rigidness of the part-baked dough pieces are recommended. For part-baked French bread Bonnardel et al. (1990) suggested a slight reduction in the amount of water added at the dough stage. A slightly tighter dough is recommended to encourage the product to maintain a circular cross-section as opposed to one which is oval in appearance. Stear (1990) considered that dough water absorption must be reduced to give a stiff dough which will remain rigid on removal from the oven and that a moderate reduction in yeast and yeast food helps avoid excessive oven spring. These recommendations are also given by Pyler (1988). Both Pyler and Stear consider that straight doughs require higher mixing temperatures, in the range 32–35 °C (90–95 °F). Stoecklein (1995) considered that the bread improver employed should be one with a higher level of ingredients which will confer greater dough piece stability, e.g. DATA ester.

Bonnardel et al. (1990) describe the use of baking nets with deep, flexible, rounded corrugations, in which the dough pieces can sit and helping to maintain their shape for proving, baking or freezing. For French breads a shorter final proof time is suggested by Bonnardel et al. (1990). Generally a less aerated, lower volume dough piece is favoured to help maintain the product structure. Longer final proof times produce part-baked breads with higher volumes and lower stability. It is recommended that the top surface cutting of dough pieces made from tighter doughs, with less final proof time, should be a little deeper. Kamel and Stauffer (1993) described two main methods for achieving minimum crust formation and colour. First, a low temperature for the normal baking time may be used which requires a reduction in proof time (or a reduction of yeast level) to take account of the resultant increase in loaf volume caused by the delay in the dough piece 'setting'. Second, a high temperature bake may be used to set the dough structure quickly, followed by removal from the oven before the crust has set or coloured.

The objective of the first bake is to obtain a sufficiently rigid semi-finished product which has an uncoloured surface. The ideal first bake for French-style breads is a two-stage process. For example, in a rack oven, during the first stage dough pieces are placed into a steam-filled oven at high temperature for a short time, typically 3 min at 270 °C (518 °F) to open up the cuts. The second phase is a lower temperature bake for a longer time, typically 7 min at 250 °C (482 °F) to ensure that the centre of the dough pieces have been transformed from dough into 'set' bread. Bonnardel et al. (1990) found that just after 8 min of baking at 235 °C (455 °F) the centre temperature of 170 g half-baguettes had reached approximately 87 °C (188 °F), whilst the temperature on the edge of the dough piece had nearly reached 100 °C (212 °F).

The exact temperature of an oven for baking off part-baked bread will vary with each type of oven and the size of each batch. Oven conditions during the first bake will vary additionally with the size and shape of the dough pieces. A pragmatic approach to determining the optimum conditions during the first baking period is to adjust the baking time and temperatures until the disappearance of an unbaked ring in the centre of the dough piece, without the formation of crust and colour. Pyler (1988) considered that in order to avoid shrinkage and collapse on cooling the internal temperature ex-oven must exceed 76 °C (170 °F) and should preferably reach 82 °C (180 °F). To achieve this products must be baked at between 121 and 148 °C (250–300 °F) for as long as possible without the formation of crust colour. Turner (1970) considered that 90 °C (195 °F) was the proper internal temperature of part-baked rolls. For maximum rigidity and volume, without crust formation, a 10–15 min bake at a steady 140 °C (284 °F) to a core temperature of 82 °C (179 °F) should be given (Stear 1990).

Post-baking Handling and Storage

Part-baked bread has a much higher moisture level than fully-baked bread. Bonnardel et al. (1990) reported weight losses for part-baked bread after the first baking and cooling of only 13.5 % compared to up to 22.5 % for fully-baked French bread. The higher moisture content of part-baked products makes them susceptible to mould growth (Kamel and Stauffer 1993). Strict plant hygiene procedures should be implemented to reduce mould contamination. The shelf-life of part-baked bread without any further processing is limited. The addition of mould inhibitors (see Chap. 3) to the dough and the use of sprays with mould inhibitor solutions after baking are commonly used.

Modified atmospheric packaging (MAP) or gas flushing considerably extend the mould-free shelf-life of part-baked bread stored at room temperature (Fig. 9.6). This method is commonly employed in the retail sector. MAP involves sealing the part-baked product in a moisture-proof, airtight packaging material (Brennan and Day 2012). Before the package is sealed, the air (and thus oxygen) is replaced or flushed out with an atmosphere of carbon dioxide and nitrogen. The resultant anaerobic sealed environment cannot sustain aerobic metabolism of microorganisms. During storage at ambient temperature an increase in crumb firmness or staling occurs.

Freezing part-baked bread stops the process of staling and the development of mould. Additionally, freezing hardens the product, giving stability to an otherwise fragile product. Freezing can be carried out in a blast freezer operating at −40 ± 5 °C (−40 °F ± 9 °F). ‘Shock freezing’ can be used in which a liquid carbon dioxide or nitrogen spray rapidly freezes a thin layer of bread. This forms a barrier against moisture migration and increases rigidity before slower freezing down to −20 °C (−4 °F) (Bonnardel et al. 1990). After the freezing process the part-baked products are packaged in cardboard boxes with an inner sealable polythene liner. Frozen storage follows at −18 °C. No moisture loss was reported in part-baked breads stored under these conditions.

Fig. 9.6 Part-baked products in gas flushed-pack (courtesy *BakeTran*)

Second Bake

When correctly baked, quite acceptable bread and rolls can be produced after the second bake, and products are enjoyable when eaten before they firm up after a few hours. With appropriate training of the person carrying out the second bake, it is possible to maintain an evenly coloured crusty product. Not following closely the recommended baking procedure can lead to pale-looking unappetizing bread and rolls.

The second bake is used to reverse the staling process and the crumb regains the softness associated with fresh bread (Kamel and Stauffer 1993). However, it should be noted that after re-heating the rate of staling increases (Schoch and French 1947) so that crumb firming take place in a matter of a few hours after the second bake and this can have a significant impact on consumer perception of product quality.

Final baking brings about the following four changes:

- A dry crisp crust is formed and coloured.
- The aroma of baked bread is produced.
- The crumb of the product is refreshed reversing the process of staling.
- The volume of some products is reduced, e.g. French bread by 13–15 %.

Bonnardel et al. (1990) first reported loaf shrinkage during final baking after their investigation into part-baking of French bread. A final bake-off temperature of 210 °C (410 °F) for 10 min was given for a frozen part-baked half-baguette. The recommended baking temperature for part-baked bread in the UK is almost universally given as 220 °C (428 °F), and variations are given in time depending on size and whether the product is fresh or frozen.

It should be noted that the quality of part-baked products in never likely to exceed the quality of an optimised scratch product of the same form. Commonly the shelf life of the re-baked product is short and they are best eaten soon after re-heating. A particular problem is the second bake is out of the control of the bakery that first manufactured the product. Concern over wide variations in the interpretation of when the second bake is complete has led to the introduction of what are known in the UK as three-quarters-baked products. The degree of baking applied to three-quarters-bake products is greater than conventional part-baking and is sufficient to give some crust colour. Three-quarters-baking reduces the possibility of pale-looking under-baked bread being produced after the second bake.

Yeasted Laminated Products

Introduction

The main yeasted laminated products are croissants and Danish pastries (Fig. 9.7). Both appear to have their origin in the seventeenth century. Rijkaart (1984) describes how in 1615 the law in Vienna only allowed bakers of bread to make products containing yeast. Bread bakers made Danish pastry, which is described as puff pastry with added yeast. In Denmark, Danish pastries are called ‘Wienerbrot’ or the ‘pastry from Vienna’. Asklund (1965) gives a further account of the history and evolution of Danish pastries. Montagné (1961) considered that the origin of the croissant was in Budapest and dates from 1686. Bakers working during the night gave alarm when they heard the noise of what turned out to be Turkish invaders who had dug underground passages to reach the centre of the town. The bakers who had saved the city were granted the privilege of making a special pastry. The pastry had to take the form of a crescent, in the shape of the emblem on the Ottoman flag.

Fig. 9.7 Mini-croissant, pecan Danish and pan-au-chocolat (courtesy *BakeTran*)

Formulations

Published formulations of croissants and Danish pastries commonly contain nine major ingredients: flour, salt, water, yeast, shortening, sugar, egg, milk solids and laminating margarine or butter (not all croissant formulae contain egg). Cauvain (2001) surveyed 36 Danish pastry and 14 croissant formulations and concluded that the two products have similar 'average' essentials, although the proportion of individual ingredients varied substantially. Table 9.4 shows a comparison of the mean or average proportion of ingredients from a survey reported by Cauvain (2001). Examination of Table 9.4 indicates some general trends. Danish pastries contain lower proportions of salt and higher proportions of yeast, sugar, egg and laminating margarine/butter. The same general trend is found in Table 9.5 which compares croissant and Danish pastry formulations for American and UK products. It is clear from the details given in Tables 9.4 and 9.5 that the quality and quantity of the ingredients used play a major role in determining final product quality as they control many of the recipe and process interactions which contribute to final laminated product quality.

Table 9.4 Mean proportions of ingredients from a survey of 14 croissant and 36 Danish formulations (Cauvain 2001)

Flour (%)	Croissant	Danish pastry
Flour	100	100
Salt	1.8	1.3
Water	52.2	43.6
Yeast (compressed)	5.5	7.6
Shortening	9.7	9.6
Sugar	6.1	9.2
Egg	2.6	12.4
Skimmed milk powder	6.5	5.4
Laminating margarine/butter	50–57	62–64

Table 9.5 Comparison of an English and an American formulation for Croissants and Danish pastries

	Croissant		Danish pastry	
% flour	Sultan[a]	Brown[b]	Sultan[a]	Brown[b]
Flour	100	100	100	100
Salt	2	1.8	1.56	1.1
Water	52	55.4	50	52
Yeast (compressed)	5	4	6.25	6
Shortening	8	2	12.5	6.3
Sugar	10	2	25	9.4
Egg	24	nil	25	5
S milk pdr	5	3	6.25	4
Margarine/butter for lamination	32	45	50	50

[a] Sultan (1989), USA
[b] Brown (1985), UK

Flour

In general a flour protein of about 11.5–12.5 % (14 % moisture basis) is considered suitable for the manufacture of laminated products. The protein may come from the choice of wheat for the milling grist or may be delivered using lower protein flours which are supplemented with dried vital wheat gluten. A key requirements is that the gluten network created in the dough should have good extensibility to withstand the stretch and folding operations which are a key part of the manufacturing processes used with laminated products. Flours for Danish pastry often benefit from protein contents at the higher end of the quoted range as they have to cope with the extra expansion that come from yeast fermentation during proof. In general doughs made from stronger flours need longer resting periods to avoid excessive pastry shrinkage and distortion, unless their dough has received intensive mixing. It would appear that flour protein levels for laminated products will be plant specific. Higher protein flours tend to be more suited to make-up plants with appropriate methods of relaxation employed, while lower protein flours may be more suitable for processes with no or short resting times.

Other Ingredients

A common practice in the manufacture of laminated products is to add a low level of fat in the preparation of the base dough. The fat can be butter, margarine or shortening. In some cases the addition of paste trimmings is considered to be suitable for the delivery of base dough fat. Cauvain (2001) reported that mixing 3–6 % fat into the dough improved paste machinability by increasing the elastic properties of dough which in turn increased the paste recovery after sheeting. Higher fat levels caused croissants to be flatter and the crumb structure to become closer grained and ‘bun-like’. It has been reported (Cauvain 2001) that additions of sugar at levels between 5 and 12 % (flour weight) gave optimum pastry quality. Higher levels inhibited yeast activity and reduced pastry lift. Danish pastries with 18 % sugar tended to distort in shape and croissants tended to uncurl and show signs of internal collapse.

Laminating or Roll-in Fat

Vey (1986) suggested a classification of ‘enrichment’ of Danish pastry based on the level of roll-in or laminating fat. To every 100 parts by weight of base dough the following parts would be added for:

Lean	12.5–17	(2–2.75 oz/lb of base dough)
Medium	18–25	(3–4.5 oz/lb of base dough)
Rich	26–35	(4.75–5.5 oz/lb of base dough)

While Smith (1990) suggested the following guide based on flour as 100 %:

Lean	30
Medium-rich	40
Rich	50
Very rich	70

The storage or conditioning of the laminating fat at the correct temperature is particularly important before use. The roll-in fat should be stored in a cool place. Consistent results are obtained when the temperature of the roll-in fat before lamination is about 15 °C (60 °F) with a dough temperature of 12–15 °C (55–60 °F). Rijkaart (1984) stated that if the laminating fat is butter then it should have a temperature of not more than 14 °C (57 °F) and if shortening was used then this could be up to 18 °C (64 °F) with a dough temperature from a high-speed mixer of 24–25 °C (75–77 °F). If the roll-in fat is too warm and soft, it will not spread evenly and will tend to be absorbed in the dough. The resultant croissants and Danish have reduced volume and a poorly defined interior crumb and layering. Roll-in fat which is too hard will not spread evenly and results in variable shape, size and layering. Butter and margarines have become the most popular roll-in fat for Danish pastry production, whether produced by hand or automatic systems. Problems have developed with these shortenings used with extruding and laminating systems because they contain moderate amounts of water (around 16 %). Anhydrous margarine containing minimal amounts water and the same plastic range as regular bakers' or pastry margarine is favoured. The improved functionality of the anhydrous margarine allows usage levels of up to 25 % less than regular bakers' margarine.

In order to avoid irregular layer formation in puff pastry and variation in pastry lift and shrinkage, the roll-in or laminating fat or margarine should be plasticized prior to its use. The best paste and pastry qualities were obtained with uniform fat crystals no greater than about 5 μm in diameter within an optimum solid fat index (SFI) of between 38 and 45 %. The firmer the laminating fat the more resistant the paste to deformation after sheeting. If the solids content and the firmness of the laminating fat are too high, pastry expansion was restricted during proof and the final specific volume is low. Cauvain (2001) reported that a fractionated butter was soft, greasy and difficult to machine at 20 °C (68 °F), the fat layers in the paste were partially destroyed during lamination and croissant specific volume was low. When used at 10 °C (50 °F) the butterfat gave a firmer paste, layering remained intact and pastry specific volume remained high. Such findings suggest that for fermented laminated products it is more important that the roll-in or pastry margarine is reasonably firm and plastic during lamination but relatively soft during proof to assist pastry expansion.

Asklund (1965) considered that for Danish pastry 'summer butter, also called grass butter, is not suitable for rolling'. The amount of solid fat in butter varies throughout the year and even during some months, as feeding regimes change. Figure 9.8 is a plot of the percentage solid fat at 10 °C (50 °F) of butter throughout the year, for the period 1985–1987. It shows the considerable variation in the percentage solid fat between summer and winter months. Typically during summer months butter has a lower content of solid fat at 10 °C, i.e. between 35 and 42 %,

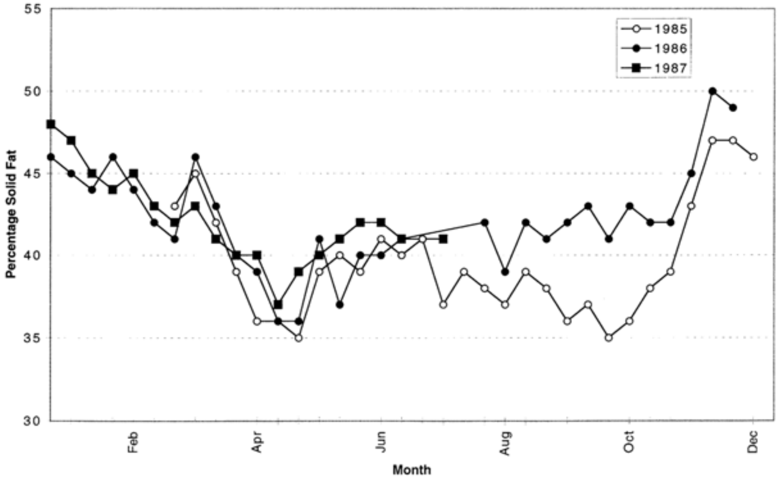

Fig. 9.8 Seasonal variation in percentage of solid fat at 10 °C (50 °F) for UK produced butteroil (courtesy D. Lawrence, Dairy Ingredients (UK) Ltd, Slough, UK)

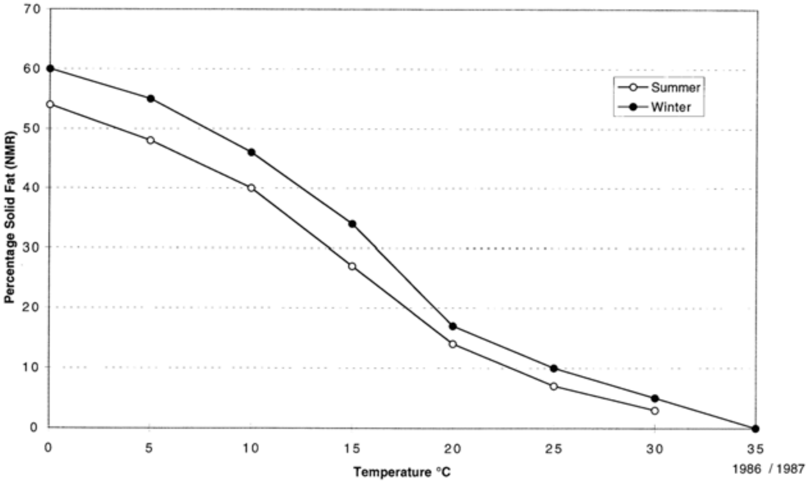

Fig. 9.9 Variation in percentage of solid fat with temperature for UK-produced butteroil (courtesy D. Lawrence, Dairy Ingredients (UK) Ltd, Slough, UK)

whereas in the winter months the percentage of solid fat is higher at 42–50 %. Figure 9.9 shows the percentage of solid fat determined by NMR on samples of winter and summer butteroil at temperatures between 0 and 35 °C. A similar trend of higher content of solid fat is found in winter butter throughout the temperature range. The important practical interpretation of these graphs is that winter and summer butter should be stored, conditioned and ideally used at different temperatures.

Kazier and Dyer (1995) described an investigation into ‘reduced-fat pastry margarine for laminated dough in puff, Danish and croissant application’. Attempts at fat reduction by lowering the amount of laminated fat proved difficult. However, by reducing the fat content of the laminate roll-in margarine, the system developed allowed a 1:1 replacement of the control roll-in shortening. Reduced-fat versions of croissants and Danish had slightly higher post-bake moisture and slightly larger volumes. The finished products using the reduced-fat system appeared to be softer and more tender eating compared to their control. In some cases emulsifiers such as diacetyl tartaric acid esters (DATA esters), sodium stearoyl lactylate (SSL) or glycerol monostearate (GMS), or a blend of GMS, lecithin and sorbitan monostearate replacing the dough fat or added to the laminating fat, increased the tender eating quality of puff pastry and offer opportunities for lowering the overall fat content of laminated products. Cauvain (2002) also reported potential benefits of DATA esters and SSL.

Dough Mixing

The basic methods available for mixing doughs for fermented laminated products are (1) low-speed straight dough, (2) high-speed straight dough and (3) the blitz system or Scotch or Dutch method. In any of these three systems, proportions of the flour can be made into a sponge and fermented prior to final dough mixing, though straight doughs tend to be most common. The degree of dough mixing and development will be plant and process specific and will depend on the characteristics required in the final product.

The common approach with base dough mixing is to limit mixing so as to yield a less well developed dough by comparison with bread manufacture. In part this is because fully developed doughs tend to have high resistance to deformation and can be elastic (i.e. shrink after sheeting) and in part because development of the dough continues during the sheeting and folding processes which follow mixing. Rijkaart (1984) found from experience that vertical high-speed mixers were suitable for mixing croissant dough, he considered that a 1 min mix was sufficient. The high-speed mixer described had a 30 kW motor which drives the mixing arms at speeds up to 380 rpm. High-speed doughs after lamination are stated as being less prone to shrinkage. Mixing systems based on lower speed spiral-type mixers are also in common use. Asklund (1965) emphasized that, in the production of traditional Danish, the dough should literally be mixed and not kneaded.

Pyler (1988) described how, when doughs were to be extruded, some adjustments were required to counteract the adverse effects of the greater abuse that is inherent in the process. These included making a sponge of up to 75 % of the flour, increasing absorption by 1–3 %, extending dough fermentation time by 30 min, maintaining a yeast level of 5 % in the sponge and an additional 3 % at the dough stage.

A key step with mixing is to deliver a dough with final temperature not to different from that of the laminating fat. Poehlman (1979) considered the controversy about the amount of mixing and development and the desirable dough temperature for Danish pastry. Some advocate long mixing and warm doughs, while others advocate short mixing and cold doughs. Both he said were right because the choice of combination depended on the product and the nature of the production line. For mixed production [in terms of size, 55–60 g (2 oz) and large 340–450 g (12–16 oz) Danish coffee cake] he believed that a short, cool mixing provided the best over-all performance. He considered that for best performance at make-up, the proper temperature for Danish dough was 12–15 °C (55–60 °F).

Methods of Adding the Roll-in or Laminating Fat to the Dough

Five methods of adding the roll-in or laminating fat to the dough are described as:

- French or English;
- Blitz, Scotch or Dutch method;
- Co-extrusion;
- Sandwich;
- Curling.

On the small-scale using either the French or English methods, the roll-in fat is placed on part of the sheeted-out dough. The remaining dough is then folded over the roll-in fat to give, in the French method, one layer of fat surrounded by dough, i.e. one layer of fat and two of dough in the paste. The English method, after the first fold, gives two layers of fat and three layers of dough in the paste. In the blitz or Scotch method, previously described, optimum pastry quality is influenced by the amount of mixing of the complete paste since the laminating fat is not incorporated as a discrete layer. Pastries produced by this method after lamination have lower lift than those made by the English or French method (Cauvain 2002).

Co-extrusion (Vey 1986) involves the extrusion of a cylinder of paste. A layer of roll-in fat is co-extruded on the inside of the cylinder of paste. The co-extruded cylinder is then passed through sheeting rollers to flatten the cylinder into a sheet of one layer of roll-in fat surrounded by dough. The continuous sheet of dough is extruded onto a moving conveyor for further processing. The sandwich process involves extruding the roll-in fat onto a base dough layer with the extrusion of a top layer of dough onto the roll-in fat. The curling process as described by Rijkaart (1984) employs just one layer of dough onto which a layer of roll-in fat is extruded covering the central portion but leaving the edges clear. Curling rollers or ploughs turn the uncoated edges to fold over the laminating fat and enclose it. This composite is gently pressed and proceeds for further processing.

Lamination

In the process of lamination the objective is to build-up a series of discrete and alternating layers of laminating fat and dough (Cauvain 2001). Commonly fewer layers are used in the manufacture of Danish and croissant pastes, compared with puff pastry. Typically Danish and croissant pastes are laminated to give between 20 and 50 fat layers, while in puff pastry there are between 130 and 250. With fewer fat layers the products have large volume but an open grain and flakier but fragile structure while increasing the fat layers beyond 48 reduces flakiness and volume and the grain became more bread-like. The reduced layering levels are required to compensate for the addition of yeast and the effects of yeast fermentation. At the microscopic level small gas bubbles are retained in the layers of the yeasted past and when they expand they destroy the layered structure was largely destroyed. The holes which are created in the gluten sheets allow the expansion gasses to escape and lift is reduced.

Automatic Production

Fully automatic make-up plants are available that can produce 12,000 curved croissants and 14,000 straight croissants/h encompassing all of the extrusion, sheeting, laminating, cutting and shaping operations that are required. Some plants may include resting periods for the pastes as part of the operation while others will be work on a continuous basis.

Proving will be carried out to expand the pastes but prover temperatures tend to be around 10 °C lower than used for bread. These lower temperatures are used in order to preserve the integrity of the fat layers which have relatively low melting points, especially if butter is used as the laminating fat. The prover humidity will also be lower than used for bread so as to limit dough flow and loss of shape.

Frozen and Fully-Proved Frozen Laminated Products

As discussed in Chap. 6, laminated doughs may be readily frozen. They can be either in the unproved or proved state. If frozen in the unproved state, then thawing and proof are required before bake-off. More convenient is the production of frozen fully-proved laminated products since they can be taken from deep freeze storage and placed immediately in the oven for baking. The loss of potential gas production by the yeast which is present in the dough is not a major problem since the steam pressure which is generated during baking is sufficient to force the dough layers apart. Good quality croissant and Danish pastries can be produced this way provided that the product recipe and manufacturing processes have been carefully controlled in the stages before the products pass into the freezer.

Hot-Plate Products

Most hot-plate goods are based on the manufacture of a batter (e.g. crumpets, pikelets) or a very soft dough (yeasted muffins) (Cauvain and Young 2006). As their name implies they are baked on a hot plate or griddle rather than in an oven and their production requires special baking arrangements to ensure that both product surfaces received equal or similar heating. This category also includes some forms of pancakes.

Batter-Based Products

Included in this sub-section are yeast-containing batters such as for crumpets and pikelets and powder-raised products, such as pancakes. A fluid batter is prepared and which is deposited directly onto the hot plate surface for baking. Crumpet products are characterised by their texture which comprises a series of tunnel-like holes which run vertically from the base of the product up to the surface without interruption. This characteristic structure can only be readily achieved using the combination of fluid, aerated batter and baking on a hot plate.

For crumpets the initial batter/soft dough may be mixed with a batch mixer and then transferred to holding tanks for a short fermentation period (around 30–60 min) to encourage yeast activity. After fermentation the batter is transferred to a depositor and individual deposits are made onto the surface of the hot plate, there is no proof before baking. As the batter is very fluid the deposits are made into a greased ring or frame which is sits directly on the hot plate surface but is part of a separate chain of linked rings. Commonly the rings are round in shape but variations are known, e.g. square in New Zealand.

Typically a hot plate oven comprises a series of slats which cover the width of the oven but are only a little longer than the size of the required product, in effect each slat is a mini hot-plate. At the end of baking the chain of linked rings is lifted from the product for re-use, the upper surface of products like crumpets, may be lightly toasted, sometimes with an infra-red grill and the removal of the products is aided by a wire or knife arrangement.

Some powder-aerated products, like pancakes, may be mixed and deposited directly onto the hot-plate and baked without the use of rings. In this case the procedures can be similar to that of cake production comprising an initial batch mixing followed by passage through a continuous aerator before depositing using manifold-type equipment. It is commonly necessary with this type of operation to turn the product over part-way through baking to ensure a uniform colouration on both product surfaces.

It is worth noting that the majority of the products in this sub-group have high water activities after baking and so their production is almost certainly going to include the requirement for handling areas of low microbial risk separated from the main production area.

Fermented Dough-Based Products

Fermented muffins are very different from cake muffins in texture and eating quality and are characterised by having a drum-like shape. In some cases the fermented muffin has a bread-like texture while in others (US English Muffin) the texture is more open and almost crumpet-like in appearance, part of the differences in texture are achieved by adjusting the consistency of the dough for processing, that is more open textures may be achieved with softer (higher water) doughs. The US English Muffin is further characterised by having a pre-fermentation or sponge system, before the main dough mixing stage in order to develop specific ‘sour dough’ notes in the final product. In this case the arrangement and control of the plant is very similar to that for the manufacture of hamburger buns.

The first stages of the manufacture of muffins are very similar to that of rolls in that a yeast-based dough is prepared in a batch mixer. A short period of fermentation in bulk may be used (typically 1 h) or the dough may pass directly to a divider and roll processing plant. After the individual pieces have been divided and shaped, they are placed in rings for a short period of proof. The arrangements with the movements of the rings may be similar to that used in the manufacture of crumpets. When the proved muffins proof and then baking. In some operations the muffins may be turned over part-way though baking on the hot-plate in order to achieve a uniform colour on both sides and in others an upper hot plate (a continuous chain of slats) is lowered down to touch the ring and so contain the expanding batter to deliver the final drum-like shape. After baking the sides of the muffin may be scored to facilitate tearing of the product are the point of consumption.

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Chapter 10
Bread Spoilage and Staling

Introduction

Bread is the most important staple food in the Western world and it is recognized as a perishable commodity, which is at its best when consumed 'fresh'. Unfortunately, bread remains truly 'fresh' for only a few hours after it leaves the oven. During storage it is subjected to a number of changes which lead to the loss of its organoleptic freshness. The factors that govern the rate of freshness loss in bread during storage are mainly divided into two groups; those attributed to microbial attack, and those that are result of a series of slow chemical or physical changes which lead to the progressive firming up of the crumb, commonly referred to as 'staling'.

Microbiological Spoilage of Bread

The most common source of microbial spoilage of bread is mould growth. Less common, but still causing problems in warm weather, is the bacterial spoilage condition known as 'rope' caused by growth of *Bacillus* species. Least common of all types of microbial spoilage in bread is that caused by certain types of yeast.

Mould Spoilage

Mould spoilage of bread is entirely due to post-processing contamination. Bread loaves fresh out of the oven are free of moulds and mould spores due to their thermal inactivation during the baking process (Ponte and Tsen 1978). Bread becomes contaminated after baking from the mould spores present in the atmosphere surrounding loaves during cooling, slicing, packaging and storage.

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The environment inside a bakery is not sterile because dry ingredients, especially flour, contain mould spores, and flour dust spreads easily through the air. It has been estimated that 1 g of flour contains as many as 8000 mould spores. In some bakeries a similar number of spores settle on 1 m^2 of surface every hour (Doerry 1990). Production operations such as weighing and mixing of ingredients increase the mould count in the air. In larger bakeries where segregation is possible, the flour handling areas are separated from the cooling and packaging area of the finished bread.

Bread crust is rather dry (Cauvain and Young 2008) and if the relative humidity of the atmosphere is below 90 %, moulds will not grow on it. Also, moulds are relatively slow to develop, so that in dry climates the surface of a slice of bread may dry before mould growth is sufficient to be visible. In a humid atmosphere, however, and especially on a loaf inside a wrapper, moulds will grow rapidly. This is true especially if the bread is wrapped hot from the oven so that droplets of water condense on the inside surface of the wrapper. When bread is cut, the inner, more susceptible surfaces are exposed to mould infection. Sliced, wrapped bread is more at risk, because the moist, cut surfaces with a water activity in excess of 0.90 are an ideal substrate for moulds to grow on and the packaging prevents the moisture loss.

The rate of mould growth in various breads depends on the recipe and the processing method (Seiler 1992). Brown, wholemeal and wholewheat breads appear to become mouldy rather earlier than white breads because mould growth is often more clearly visible on the darker surfaces. Cultured breads, such as rye bread (Chap. 13), tend to have a slightly longer shelf life because of their increased acidity and lower pH. The processing method has also been shown to have an effect on the rate of mould growth. For example, bread made from no-time dough, e.g. CBP has a slightly shorter shelf life than bulk-fermented bread. This difference is considered to be largely due to the higher alcohol content in fermented breads.

The most common bread spoilage moulds are *Penicillium* spp., although *Aspergillus* spp. may be of greater significance in tropical countries (Legan 1993). In wheat-breads a wide range of spoilage moulds including *Penicillium, Aspergillus, Cladosporium, Mucorales* and *Neurospora* have been observed (Table 10.1). *Rhizopus (nigricans) stolonifer* is the common black bread mould. It has very fluffy appearance of white cottony mycelium and black sporangia. *Neurospora sitophila* is another type of mould which is reddish in colour, and is found in bread stored at a high humidity or wrapped while still warm. Storage temperature has an effect on the type of moulds growing in bread. *Aspergillus* spp. was reported to be the dominant mould spoilage of bread in India, while the 90 % of moulds isolated from a range of bread in Northern Ireland were *Penicillium* spp. (Legan 1993).

In addition to spoilage, some moulds present a severe risk to public health because they can produce mycotoxins. Exposure to mycotoxins can occur either directly by eating bread spoiled by mycotoxigenic moulds or indirectly as a result of people consuming the products of animals fed contaminated bread. Mycotoxins are very resistant and can survive the heating process designed to kill moulds. It has been reported that 10 % of *Aspergillus* spp. and *Penicillium* spp. are toxic to mice (Silliker 1980). As a significant amount of mould growth is needed to form mycotoxins in

Table 10.1 Characteristics of bread moulds

Mould	Colony colour	Colony appearance	Comments
Penicillium spp.	Blue/green	Flat, spreads rather slowly	The most common type of bread mould
Aspergillus niger	Black	Fluffy, spreading with spore heads often clearly visible	Frequently present
Aspergillus flavus	Olive green		
Aspergillus candidus	Cream		
Aspergillus glaucus	Pale green		
Cladosporium spp.	Dark olive green	Flat, spreads slowly	Often present on damp bakery walls, commonly encountered
Neurospora sitophila	Salmon pink	Very fluffy and fast spreading	Will grow very rapidly on moist bread
Rhizopus nigricans	Grey/black	Very fluffy and fast spreading	Will grow very rapidly on moist bread
Mucor spp.	Grey		

Source: Seiler (1992)

bread, the risk to public health from mycotoxins in developed countries is minimal (Legan 1993). The consumer today tends to reject the whole loaf rather than cut away the visibly mouldy portion and eat the remainder, as was common in the past. The indirect risk via animals fed on mouldy bread is also very low (Osborne 1980).

Bacterial Spoilage

Rope is a spoilage problem of bread and other bakery products that have high equilibrium relative humidity (ERH), i.e. greater than 90 %. It is caused by a mucoid variant of *Bacillus subtilis* or *Bacillus licheniformis*. The causative organism, *Bacillus subtilis*, appears naturally in the soil and thus rope bacteria may be present on the outer parts of grains and vegetables. It can also be present in the air and may be carried as an aerosol in dust in the bakery environment. The primary source of contamination is from raw ingredients that may be present in or on the equipment. In bakeries a potential source of rope spores are process bread crumbs and bread returns, the latter should be well separated from production areas. The practice of re-using bread crumbs at the dough mixing stage should be discouraged to limit the potential for the development of rope.

Almost any of the ingredients used in the production of bread may contribute the organisms, but flour and equipment that previously have been in contact with contaminated dough are the greatest offenders. According to Clark (1946), rope occurs during hot and humid weather. The spores easily survive baking and germinate and grow within 36–48 h inside the loaf to form the characteristic soft, stringy, brown mass with an odour of ripe pineapple or melon. This is due to the release of volatile compounds including diacetil, acetoin, acetaldehyde and isovaler-aldehyde which contribute to the typical sweetish odour of rope (Legan 1994). The bacteria are heavily encapsulated, which contributes the mucoid nature of the material. As spoilage progresses, bacterial amylase and proteases degrade the bread crumb, causing discoloration and development of stickiness. At this stage the crumb stretches into long silky threads which give rise to the name ‘rope’. Conditions favouring the appearance of rope are (1) a slow cooling period or storage above 25 °C (77 °F), (2) pH above 5, (3) high spore level and (4) a moist loaf. The water activity inside a loaf is marginal for *B. subtilis* growth so that rope may appear in localized areas where the moisture content is high. The development of rope has become rarer in many countries because the addition of calcium propionate and acetic acid (Cauvain and Young 2009), good hygiene (sanitation) and good bakery practice keep it under control. However, in the parts of the world where salt levels are being reduced (e.g. the UK) there is an increased risk of rope growth, especially if inhibitors are not used in the dough recipe.

Yeast Spoilage

Many of the complaints regarding off-odours in bread, when not due to rope, are associated with yeasts. Contamination with wild yeasts is rare in bread made using short processes, but can sometimes occur when long fermentation sponges or doughs are employed (Seiler 1993). Yeasts, like moulds, do not survive the baking process, but bread can become contaminated with yeasts during the cooling and slicing operations. The main sources of contamination are through physical contact with dirty equipment or infected high-sugar foods, which are a perfect substrate for osmophilic yeasts.

There are mainly two types of yeasts involved in the spoilage of bread (Legan and Voysey 1991).

- Fermentative yeasts. Sugars present in bread are fermented by these yeasts. The spoilage is manifested by the development of an ‘alcoholic’ or ‘estery’ off-odour depending on the species of yeast present. Many different types of yeast are capable of growing on bread and causing such defects but *Saccharomyces cerevisiae,* which is the bakers’ yeast, tends to be encountered most often in bread.
- Filamentous yeasts. These are commonly referred to as ‘chalk moulds’ because they form a white, spreading growth on the surfaces of bread which can readily be confused with mould growth. They are considered as yeasts rather than moulds since they produce single cells and reproduce by budding. There are a number of different chalk moulds, but the most common and troublesome is *Pichia burtonii* which has the ability to grow very fast on bread and has proved to be more resistant to preservatives and disinfectants than many other moulds.

Table 10.2 Anti-mould agents most commonly used in bread

Anti-mould agents	Recommended level of use (%)[a]
Propionic acid	0.1
Calcium propionate	0.2
Sodium propionate	0.2
Sodium dipropionate (70 % solution)	0.2

[a] % of flour weight

Control of Microbiological Spoilage

Preservatives

The preservatives most commonly used in bread to prevent or minimize microbial growth are the propionates, i.e. propionic acid and its salts (Chap. 3). Organic acids such as propionic acid act by distorting the pH equilibrium of microorganisms (Wagner and Moberg 1989). The depression of the internal cellular pH by ionization of the acid molecules leads to the elimination of substrate supplies into the cell, causing inhibition of the microbial growth (Jay 1992). The anti-microbial activity of propionates is mainly against moulds and the bacteria responsible for the development of rope in bread. Because their effectiveness on yeasts is minimal, propionates can be used in bread without disturbing the leavening activity in the dough (Beuchat and Golden 1989). The types of propionates used in bread with their recommended levels of use are listed in Table 10.2.

Post-baking or post-cooling it is possible to use preservatives sprayed onto the surface of the bread. This avoids the adverse impact of the preservatives on yeast fermentation. Recently an approach which has been recent advocated is to use special cold-adapted enzyme systems such as chitinase to act as a ‘natural preservative which is applied to the bread post-baking or cooling (Guttmann et al. 2014). The application of post-baking or cooling sprays suffer from the fact that it is difficult to apply the solution equally to all of the exposed surfaces without sophisticated handling systems. New methods which have been suggested for mould control (Magan et al. 2012) include synthetic anti-oxidants (such as butylated hydroxytoluene), essential oils (such as clove, cinnamon, thyme) and biopreservatives (based on lactic acid bacteria).

Another substance with effective preservative action in bread is ethyl alcohol. The addition of ethanol at levels between 0.5 and 3.5 % of loaf weight leads to a substantial extension of the shelf-life of bread (Legan 1993). Seiler (1984) has demonstrated that the mould-free shelf-life of loaves treated with alcohol increases with ethanol concentration, such that a 50 % extension in life can be achieved with a 0.5 % addition of ethanol based on loaf weight (Fig. 10.1). Similar increases in shelf life were obtained when the same amount of ethanol was sprayed over all surfaces of the loaf prior to packaging and sealing as when it was added to the base of a bag of the same size before adding the product and sealing. This finding confirms that ethanol acts as a vapour pressure inhibitor. Sensory tests have indicated that a level of addition higher than 1 % by product weight might be unacceptable by the

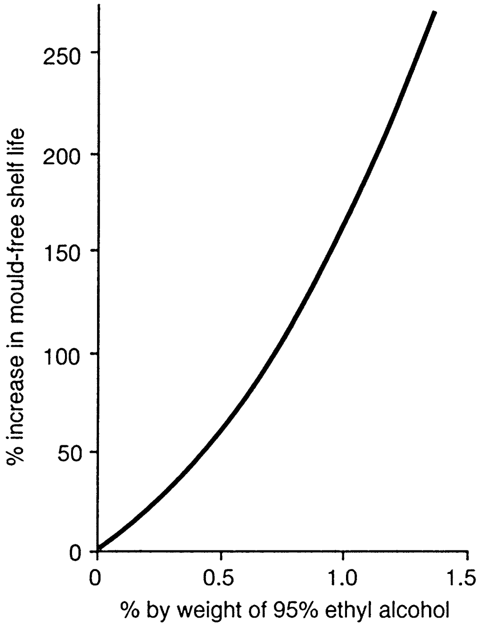


Fig. 10.1 Relationship between alcohol concentration applied and percentage increase in mould-free shelf life (source: Seiler 1984)

consumer (Seiler 1984). Despite the high cost of duty paid, ethanol has real potential as a bread preservative not only because of its anti-microbial activity but also its ability to delay staling. However, in some parts of the world the use of ethyl alcohol cannot be used for ethical or religious reasons.

Modified Atmosphere Packaging (MAP)

The storage of food in atmospheres of increased concentration of carbon dioxide is referred to as modified atmosphere. The application of MAP (Brennan and Day 2012) in bakery products became of interest in the late 1970s, mainly in Europe because new labelling regulations demanded that the presence of preservatives should be declared. In contrast, carbon dioxide and nitrogen do not need to be declared. In addition, there was a need for greater increases in shelf-life than were possible using propionates. Packaging in carbon dioxide has the advantage that it can increase the shelf life of bread without affecting its flavour, aroma or appearance. A carbon dioxide atmosphere is effective in retarding the development of moulds when present in concentrations greater than 20 % (Seiler 1984; Inns 1987). At concentrations near to 100 % the anti-microbial effect of carbon dioxide is maximized through anaerobiosis.

It has been shown that the higher the concentration of carbon dioxide in the atmosphere within the package, the greater the extension of the mould-free shelf-life (Seiler 1984). Studies carried out on British bread have indicated a shelf-life extension of 100, 200 and 300 % in packed atmospheres of 40, 60 or 90 % carbon

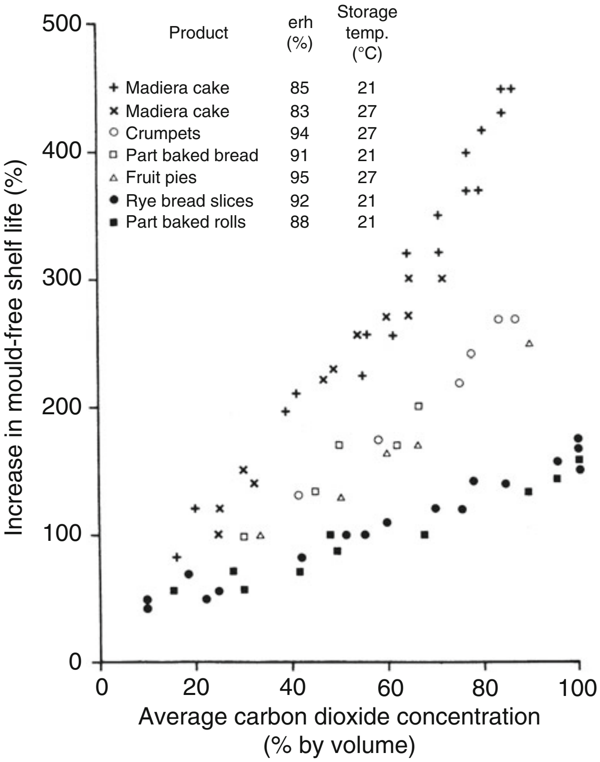


Fig. 10.2 Increase in mould-free shelf life of various products with different carbon dioxide concentrations in the headspace of the pack (source: Seiler 1984)

dioxide by volume (Seiler 1984, 1989). The effect of carbon dioxide on the mould-free shelf-life of products is ERH dependent. Bakery products such as cakes, with ERH values of 85 % or below, can obtain 400 % extension in their shelf-life in atmospheres of 75 % or above of carbon dioxide. In bread-type products, which have an ERH higher than 90 %, when a high concentration of carbon dioxide is present the achieved extension is about 250 % (Fig. 10.2). A mixture of two gases, carbon dioxide and nitrogen, has also been used as a means of preventing package collapse, which can happen as carbon dioxide is absorbed into the product when it is used as the sole gas in MAP. A gas mixture of 60 % carbon dioxide and 40 % nitrogen has been found to be the most suitable (Ooraikul 1982).

The main methods of wrapping products under modified atmosphere conditions are (Seiler 1984):

- Form-fill sealing, where the air is replaced by a continuous stream of gas prior to the sealing of the package. The advantages of this system are the speed of the operation, versatility and the ability to adjust to different product sizes and wrapping materials. The disadvantage is a significant tendency towards gas leakage at the point of seal. The control of sealing pressure, time and temperature is absolutely necessary to avoid this gas leakage.

- Vacuum packaging, where the air is removed by creating a vacuum inside a partially sealed package, followed by the addition of the desired gas mixture. This is a less flexible system which requires a two-step approach to replace the air. However, this method can attain an equilibrium carbon dioxide concentration within the package approaching 100 % and can even produce gas-tight seals between the lid and the base.

The application of gas packaging in bread-type products is mainly limited in high-value bread-type products intended to have long storage life because of the cost of gas, special wrapping equipment and the laminated films used in the process.

Irradiation

Irradiation is used as a means of destroying mould spores which may be present on the surfaces of bread. The types of irradiation of primary interest in bread preservation are ultraviolet, microwave and infrared (Seiler 1983; Grandison 2012).

Ultraviolet Irradiation

Ultraviolet (UV) light is a powerful anti-bacterial agent with the most effective wavelength being about 260 nm. UV light is used to control the occurrence of mould spores on bread. The poor penetrative capacities of UV light limits its use to surface applications. Direct UV irradiation is used to treat the surfaces of wrapped bakery products, leading to useful increases of the mould-free shelf-life. The important advantage of UV light is that it does not generate heat to destroy wrapping films or promote condensation problems. The disadvantages are that it is difficult to treat a multi-surfaced product as mould spores in the air cell walls within the bread surface are protected from the irradiation. There is also the risk of exposure and it is necessary to shield the UV light from workers' eyes (Seiler 1989). UV light may be used immediately products leave the oven or are depanned, in the cooler or during slicing.

Microwave Radiation

Microwaves lie between the infrared and radio frequency portion of electromagnetic spectrum. The main advantage of microwave heating is that microwaves heat rapidly and evenly without major temperature gradients between the surface and the interior of homogeneous products (Potter 1986). Seiler (1983) reported that wrapped bread can be rendered mould-free by heating in a microwave oven for 30–60 s, which is the time required for the surface to reach 75 °C (167 °F). The use of microwaves as a means of bread preservation is limited by the heating effect which results from their use. This can cause condensation problems which can adversely affect the appearance of the product.

Infrared Radiation

Infrared treatment can be used to destroy mould spores on bread by heating surfaces to the desired temperature of 75 °C without adversely affecting the quality and appearance of the product or the integrity of the packaging material (Seiler 1968). The time required to reach this temperature depends on the thickness of the packaging material, the nature of the product and the distance between the infrared projector and the surface of the product. The advantage of infrared radiation over microwaves and UV is that it is necessary to heat only the outside surfaces, which minimizes problems due to condensation or air expansion. One disadvantage is that it is quite costly for multi-sided products which are required either to rotate between heaters or to be treated in two separate ovens (Seiler 1983).

Bread Staling

The term ‘staling’ refers to the gradually decreasing consumer acceptance of bread due to all the chemical and physical changes that occur in the crust and crumb during storage excluding microbial spoilage (Bechtel et al. 1953). The result of these changes is a product which the consumer no longer considers ‘fresh’. Staling is detected organoleptically by the changes in bread texture, as well as in taste and aroma.

The processes that cause staling actually begin during cooling, even before starch has solidified sufficiently for the loaf to be cut. Bread staling is mainly associated with the firming of the crumb. During storage, the crumb generally becomes harder, dry and crumbly, and the crust becomes soft and leathery. Quite often, these changes are solely attributed to the drying out of the crumb. However, the mechanism of crumb firming during storage is far more than a simple moisture redistribution from crumb to crust. The term bread staling embraces a series of complex and interrelated events (Rayas-Duarte and Mulvaney 2012) though the overall staling process is commonly described as comprising two separate sub-processes: the firming effect caused by moisture transfer from crumb to crust, and the intrinsic firming of the cell wall material which is associated with starch re-crystallization during storage.

Crust Staling

During the storage of bread, the moisture content of the crust increases as a result of moisture migration from the crumb to the crust. With an initial moisture content of only 12 %, the crust readily absorbs moisture from the interior crumb, which has a moisture content about 45 %. It has been reported (Czuchajowska and Pomeranz 1989) that during a storage period of 100 h, the crust moisture increased from 15 to 28 %, while the crumb moisture loss was only from about 45 to 43.5 %. In a zone near the crust the decrease was much more pronounced, from about 45 to 32 %. Wrapping of bread loaves in moisture-proof film accentuates crust staling by preventing evaporation of moisture that has migrated to it from the centre crumb. It must be said, however, since packaging slows down the rate of crumb staling by preventing excessive drying and minimizing the total moisture loss from the product into the atmosphere, that loaves are usually wrapped as soon as they cool. Generally, crust staling is less objectionable to consumers than the age-related firming of the crumb.

Role of the Main Bread Components in Crumb Staling

Starch

The changes that especially starch polymers undergo during the baking process and during storage determine the structure, textural properties and keeping quality of bread. A loaf of bread consists of about 50 % starch, 40 % water and 7 % protein. The main ingredients of bread are flour and water, with small quantities of fat, salt, various improvers and yeast. Starch is the major component of flour, being about 75 % of the material and plays an important role in the structure formation, physical properties and keeping quality of bread. Bread will stale even when there is no net loss of moisture from the loaf (Boussingault 1852). The mechanisms of bread staling have been studied for over 150 years. As early as 1852, the Frenchman Jean-Baptiste Boussingault, a pioneer in the study of nitrogen fixation, showed that bread could be hermetically sealed to prevent it from losing water, and yet still go stale. He further established that staling could be reversed by reheating the bread to 60 °C (140 °F), the temperature region at which, we now know, starch gelatinizes in bread.

Early researchers emphasized the role of starch in the staling process. The most comprehensive studies on changes in ageing bread were carried out by Katz (1928), in his effort to counteract staling to eliminate the need for night baking in Dutch bakeries. Katz utilized an X-ray diffraction technique to demonstrate that starch in bread retrograded with time in a manner similar to that of a starch gel. He concluded that water was involved in increased starch crystallinity, and thus starch was mostly responsible for crumb firming. Since the work of Katz, much of the work on bread staling has concentrated on the gelatinization and retrogradation behaviour of the starch fraction. A brief description of these processes is in order at this point.

Starch Gelatinization

Starch occurs as roughly spherical granules in wheat flour. The starch polymer consists of two structurally distinct polysaccharides: amylose and amylopectin. Amylose is an essentially linear polymer, apparently amorphous, containing approximately 4000 glucose units. Amylopectin—the partially crystalline component—is a multi-branched polysaccharide composed of approximately 100,000 glucose units. In the starch granules the polymer chains are held by crystalline junction points in a rigid network. Schoch (1945) separated and described the properties of the amylose and amylopectin fractions of starch.

Native starch granules are not soluble in cold water but, when heated in an aqueous medium, will absorb water and swell. Initially, swelling is reversible but it becomes irreversible as temperature is increased, and the granule structure is altered significantly. As temperature increases, the starch polymers vibrate vigorously, breaking intermolecular bonds and allowing their hydrogen bonding sites to engage more water molecules. The water penetration leads to an increased separation of starch chains, which has an effect in increasing the randomness and decreasing the number and size of crystalline regions. Continued heating results in complete loss of crystallinity. At this stage the viscosity of the system is very close to that of near-solid system, as the melting temperature (T_m) value is exceeded. This point is regarded as the gelatinization point or gelatinization temperature. In bread it is the setting temperature, when the viscous dough changes to a solid sponge. In most baked products the starch crystallites melt at between 60 and 90 °C (140–194 °F).

On cooling, all the polymers begin to lose mobility as the baked crumb cools and the viscosity increases. In bread, textural properties such as firmness will be determined by the concentration of polymers, particularly starch and the temperature. The state of starch granules in the final loaf may range from being almost fully gelatinized to a complete loss of order and with variable degrees of exudation of granular polysaccharide (mainly amylose). The exuded polysaccharide would behave physically as a rubber while the amylopectin internal to the granule would likewise be in rubbery (flexible) state. At water contents greater than 20–30 % w/w, such as that of bread, this would lead to retrogradation.

Starch Retrogradation

The predominant mechanism of staling is the time-dependent re-crystallization of amylopectin from the completely amorphous state of a freshly heated product to the partially crystalline state of a stale product. Starch retrogradation is a process in which gelatinized starch molecules re-associate to form a double helix crystalline structure. An implicit requirement of starch re-crystallization is the availability of sufficient moisture, at least locally within the matrix, for mobilizing long polymer chain segments. The rate and extent of starch re-crystallization are determined primarily by the mobility of the crystallizable outer branches of amylopectin (Schoch and French 1947; Ring et al. 1987; Russell 1987). Water plays a very important role because it acts as a plasticizer. A plasticizer is a ‘material incorporated in a polymer to increase polymer’s workability, flexibility or extensibility’ (Levine and Slade 1990). Water is unique in that role because of its low molecular weight.

Schoch and French (1947) proposed a model that describes the heat-reversible aggregation of amylopectin as the principal cause of bread staling (Fig. 10.3) and the significant role of this model in determining staling remains relevant today. They suggested that granule swelling is restricted by the limited water available in bread dough, so that swollen granules retain their identities as discrete particles. With increasing swelling the linear amylose fraction becomes more soluble and diffuses into the aqueous phase, forming a concentrated solution. Immediately on

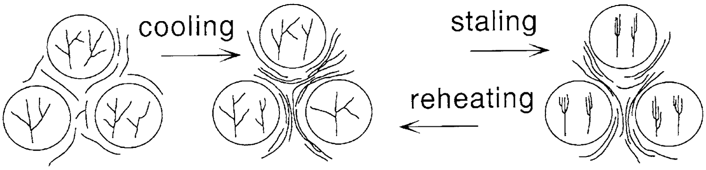


Fig. 10.3 Mechanism of bread staling (source: Schoch and French 1947)

cooling, this solution of amylose molecules associates by hydrogen bonding and rapidly retrogrades to set up an insoluble gel, contributing to the loaf structure. This gel is considered to remain stable during further storage and not to participate in the longer term staling process. As illustrated in the Schoch and French model (Fig. 10.3), amylose quickly associates in bread soon after baking, affecting initial firmness and therefore sliceability, but plays no further role in crumb firming. This firming is attributed to changes in the physical orientation of the branched amylopectin molecules of starch within the swollen granule. In fresh bread, the branched chains of amylopectin are unfolded and spread out within the limits of available water. These chains of the amylopectin polymer gradually aggregate, aligning with one another by various types of intra-molecular bonding. This effect results in increasing rigidity of the internal structure of the swollen starch granules causing crumb hardening.

Ghiasi et al. (1984) investigated the effect of varying the ratio of amylose to amylopectin on the bread firming rate. They found that on day 1 of storage the high amylopectin breads (ratio of 83.4 % amylopectin to 16.6 % amylose) were less firm than the control (ratio of 75 % amylopectin to 25 % amylose), but by days 3 and 5 the firmness of high amylopectin breads was equal to that of the control. This demonstrates that amylose retrogradation occurs rapidly and that any subsequent firming does not involve the amylose fraction. When waxy barley starch (100 % amylopectin) was used to replace normal maize starch in a reconstituted bread dough, bread loaves collapsed on cooling (Hoseney et al. 1978). This finding suggests that the amylose fraction is predominately responsible for the setting of crumb structure. The findings that the amylose in wheat starch is the component contributing most to bread staling has led to consideration that waxy wheats may be used to extend shelf life (Graybosch 1998) but bread staling is a series of complex changes to many components in the bread formulation, and so such a consideration cannot be considered in isolation.

Although a qualitative correlation exists between the extents of starch retrogradation and the increased firmness of the bread crumb (Eliasson 1985), the correlation changes significantly when different bread recipes are considered. Factors that complicate the real situation include the degree of starch granule swelling, hydration of starch, the level and type of saccharide ingredients, moisture content, the presence of solutes (salt and sugar), the presence of flour hydrocolloids (pentosans) the effects of various lipid materials and the presence of anti-staling emulsifiers. This confirms that coexistent phenomena contribute to the overall increase of firmness.

Gluten

Although starch re-crystallization is the major component of bread crumb firming, there is evidence that some other mechanisms may also have a role in the staling phenomenon. Many investigators have supported the view that gluten proteins participate in the staling process. It has been suggested (Martin et al. 1991; Martin and Hoseney 1991) that hydrogen bond interactions between the –OH groups of protruding starch chains with the $–NH_2$ groups of protein fibrils increase in number and cumulative strength through storage time as the crumb loses kinetic energy, resulting in increasing crumb firmness.

According to Kim and D'Appolonia (1977a, b) there is, in general, an inverse relation between protein content and staling during storage of bread. Bread made from strong flour, forming gluten of adequate quantity and quality, has a higher volume and a slower rate of staling compared to bread made with weak flour. This finding was later confirmed by He and Hoseney (1991), who reported that gluten from poor-quality flours interacts more strongly with the starch granules than does the gluten from good-quality flours. This means that bread from poor-quality flours would be expected to firm at a more rapid rate. Willhoft (1973a) suggested that the anti-firming effect of increased protein is due to the dilution of the starch component and an increase in loaf volume affected by gluten enrichment.

Water Redistribution

The redistribution of moisture during bread storage and its contribution to staling has been a controversial subject. Willhoft (1973b) suggested that crumb firming involved a loss of moisture from the gluten to the starch phase, whereas Cluskey et al. (1959) supported the view that moisture must migrate from starch to gluten in staling bread. Wynne-Jones and Blanshard (1986) demonstrated that 'bound' water increased slightly upon ageing of bread while 'free' water decreased. This finding was taken as an indication that moisture from gluten is moving to the crystalline starch structure. Leung et al. (1983) suggested that as starch changes from the amorphous state to the more stable crystalline state, water molecules become immobilized as they are incorporated into the crystalline structure, resulting in decreased water mobility during the ageing process. Slade and Levine (1987) proposed a possible explanation to the controversy of the direction of moisture migration within the bread crumb. They suggested that the re-crystallization of amylopectin within swollen starch granules leads to the development of a partially crystalline structure with B-type crystalline regions. Water must migrate within the crumb to the developing crystalline regions. The B-type starch crystal is a higher moisture crystalline hydrate than is A-type starch and requires the incorporation of more water molecules into the crystalline region while starch chain segments are realigning. Once incorporated within the crystal, water is no longer available as a plasticizer of the starch–gluten network, nor can it be perceived organoleptically. As a result, bread loses softness and develops a drier mouth feel. Rogers et al. (1988) have shown that retrogradation (due to amylopectin) could be affected by the presence of water, which would result in a variable firming rate. They found that bread crumb firms more rapidly under conditions where starch does not retrograde and concluded that starch retrogradation and crumb firming do not correlate with each other across varying moisture contents.

The re-distribution of water at both the macro and microscopic level has a profound effect on the staling of bread. In general terms the higher the water level that remains in bread after baking the slower the staling. The moisture content of the baked product is profoundly influenced by the level of water added during mixing and is profoundly influenced by the subsequent processing of dough to bread. A major impact at the macro level is the relationship between the product crust and crumb. Cauvain and Young (2008) showed how an increase in the thickness of the crust on a UK-style sandwich loaf from 1 to 2 mm would at equilibrium result in an extra 1.2 % moisture being lost from the crumb. This increased loss of water from the crumb would not only yield a slightly firmer/drier eating product but one which would stale slightly faster.

Chinachoti (2003) discussed the mobility of water in bread and the conflicting theories that exist. The addition of glycerol (Baik and Chinachoti 2001) caused more rapid firming of bread crumb despite potential plastization and reduced amylopectin re-crystallization. The addition of glycerol increased the diffusive mobility of water and the impact of the glycerol was to draw water from the starch and gluten macromolecules. Despite extensive studies on the role of water in bread staling the underlying mechanisms involved remain relatively poorly understood. In part this is because of the complex nature of bread crumb and its associated characteristics. In this context the impact of the role of cell structure, i.e. the sizes and distribution of cells, and moisture diffusion at macro and micro-levels has not been addressed. The contribution of product density and thickness of the cell walls in the crumb with respect to the diffusion on water throughout the structure has yet to be fully considered.

Staling Inhibitors

Losses which result from bread staling are of great economic importance, especially under conditions of industrialized and centralized production. Thus considerable attention has been focused on this problem and much research effort has been expended on understanding the mechanisms by which certain groups of ingredients retard the staling process or minimize its effect.

Enzymes

It has been known for some time that the addition of *alpha*-amylases to the dough retards crumb firming (Miller et al. 1953). During baking, amylases partially hydrolyse starch to a mixture of smaller dextrins. The *alpha*-amylase enzymes cannot access intact starch granules, thus they essentially hydrolyse damaged starch by attacking *alpha*-(1,4) linkages along starch chains. This action is stopped at *alpha*-(1,6) branch points of amylopectin. Below 55 °C (131 °F) the activity of *alpha-amylase* is minimal and depends on the amount of damaged starch in the flour. Between 58 and 78 °C (136–172 °F) gelatinizing starch is rapidly attacked, with the rate of conversion slowing down above this temperature range because of enzyme denaturation.

Bacterial *alpha*-amylase affects bread crumb firmness more than fungal or cereal *alpha*-amylase because it is more heat stable than the other two types. The thermostability of added *alpha*-amylases decreases in the following order; bacterial > cereal (malt) > fungal (Herz 1965; see also Chap. 3). As much as 20 % of the initial bacterial enzyme activity can survive the baking process. The use of *alpha*-amylase enzymes results in the formation of increased amounts of dextrins which can be extracted from the bread crumb. The amount of soluble dextrins present in the crumb is an indicator of the thermostability of the enzymes used.

The shorter-chain dextrins of a particular low degree of polymerization (DP 3–9) are presumably responsible for the anti-firming effect (Martin and Hoseney 1991). These mobile dextrins may interfere with and prevent the development of hydrogen bonds between starch granule remnants and the continuous gluten network. This action prevents the development of entanglements between starch and protein which increase the rigidity of the crumb. Lineback (1984) observed that bread made with bacterial *alpha*-amylase remains soft for longer than ‘normal’ bread. He suggested that the lower molecular weight branched dextrins have a decreased ability to retrograde or interfere with retrogradation in some manner, thus reducing the extent of firming.

Comparison of the X-ray patterns of fresh and stored breads has indicated that the order of decreasing degree of starch crystallinity was bread with bacterial *alpha-amylase*, bread with fungal *alpha*-amylase, bread with cereal *alpha*-amylase, and un-supplemented bread (Dragsdorf and Varriano-Marston 1980). Dragsdorf and Varriano-Marston (1980) observed that in bread supplemented with bacterial *alpha-amylase*, an A-type crystal pattern was obtained, whereas in the other supplemented breads the B-type crystal pattern was formed. They also noted that the crystallization of starch did not follow the change in firmness and reported that starch crystallinity and bread firming were not synonymous. The discrepancies between X-ray diffraction data and firmness results arise because the different types of crystals influence the distribution of water within the crumb differently. The A-type crystal contains eight water molecules, whereas the B-type crystal contains 36 water molecules. As a result, in breads amylopectin recrystallization develops B-type crystalline regions and the crumb is firmer because more water has migrated into the crystalline region. This water which participated in the formation of the crystal is no longer available as a plasticizer of the starch–gluten. Macroscopically, the lack of the plasticizing effect from water results in firmer bread which is perceived as being drier (Slade and Levine 1987).

There are around 1–2 % of lipid materials in wheat flour which can be classified into polar and non-polar forms. Lipase enzymes modify wheat flour lipids by splitting off fatty acids (Rittig 2005). The additions of lipase and phospholipase enzymes have been shown to reduce the rate of bread staling with the view being that the hydrolysed polar lipids which result from their actions have similar effects to emulsifiers (e.g. glycerol monostearate—see below). There are also claims that the addition of lipases improves dough machinability (Kornbrust et al. 2012).

Emulsifiers

Emulsifiers are used in bread as means of maintaining crumb softness for longer by retarding the process of staling. The emulsifiers that are widely used for their ability to reduce the staling of the bread crumb are distilled, saturated monoglycerides (see Chap. 3). Other types of emulsifiers that are effective as crumb softeners are sodium or calcium stearoyl-2-lactylate (SSL and CSL) and diacetyl tartaric acid esters of monoglycerides (DATA esters), although generally not to the same degree as monoglycerides (Tamstorf et al. 1986). The anti-staling ability of emulsifiers is mainly due to their interaction with starch. Emulsifiers complex with linear amylose, and they may do some complexing with the outer linear branches of amylopectin (Knightly 1977). It appears that the formation of an emulsifier and amylose complex contributes to a decrease in the initial firmness of the crumb, while a complexing with amylopectin results in a distinct reduction in the rate of firming during storage (Knightly 1988). Research studies have shown that when emulsifiers are added to a starch gel or to bread, the DSC (differential scanning calorimetry) endotherm due to re-crystallization of amylopectin is decreased (Russell 1983a, b; Eliasson 1983). However, it has been demonstrated that the final extent of retrogradation is not changed by the addition of emulsifiers, but the staling process proceeds at a much slower rate (Krog et al. 1989). According to Rao et al. (1992), although emulsifiers inhibit the process of amylopectin re-crystallization, they have no effect on the cellular mechanical properties of bread as measured by recoverable work. This means that emulsifiers have an effect on crumb softness but do not interfere with changes in the rigidity and elasticity of the cell walls in baked bread.

Distilled monoglycerides are commonly used as anti-staling agents in the form of hydrates. These are suspensions of monoglyceride crystals (*beta*-form), usually 20–25 % in water, with a creamy texture which make them easily dispersible in dough. Blends of saturated and unsaturated monoglycerides in the form of fine powder are also available and can be added directly to the dough.

Pentosans

Pentosans, which are non-starchy polysaccharide materials, are a minor component of wheat flour present at the 2–3 % level, roughly half water-soluble and half water-insoluble. The presence of pentosans reduces the tendency of the starch components towards re-crystallization because they are highly hydrophilic and absorb six or seven times their weight in water (see Chap. 11). A number of researchers have investigated the effect of pentosans on staling rates and concluded that they retard starch retrogradation, especially the water-insoluble fraction (Kim and D'Appolonia 1977c, d; Jankiewicz and Michniewicz 1987). They suggested that pentosans affect the extent of retrogradation by reducing the amount of starch available for retrogradation in the system. The water-soluble fraction appeared to interact with the amylopectin, and the insoluble fraction with both the amylose and amylopectin (Kulp and Ponte 1981).

Alcohol

It is generally accepted that breads produced from processes involving a bulk fermentation step have longer shelf life than do products from 'no-time' accelerated processes (Chap. 2). This is mainly due to the presence of larger quantities of alcohol which is a product of the longer periods of yeast fermentation in bulk-fermented doughs though the moisture content of breads made by bulk fermentation is often slightly lower than that from no-time doughs.

Studies carried out on the effect of ethanol on the firming of bread have shown that the crumb modulus of bread which has been treated with ethanol increases during storage at a slower rate than that of untreated 'control' loaves (Fig. 10.4). DSC has been used to follow changes in the rate of development of an endotherm associated with the starch fraction of bread during ageing, as a result of ethanol treatment (Russell 1982). The loaves were treated by painting their surface with ethanol after they had been baked and allowed to cool. The rate of development of the staling endotherm caused by the re-crystallization of starch was lower for bread treated with alcohol than for the untreated control. For comparison, crumb compressibility measurements were carried out and the results confirmed that alcohol-treated bread exhibits a reduced rate of crumb firming paralleled by changes

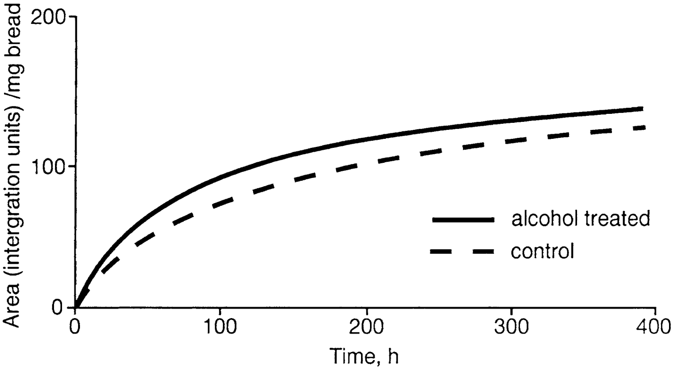


Fig. 10.4 Effect of alcohol treatment on the extent of starch recrystallization during storage (as expressed by the endotherm area per mg of bread) (source: Russell 1982)

observed by DSC in the starch fraction of the bread crumb. The manner in which the alcohol exerts its ‘anti-staling’ effect is uncertain, although it has been suggested that ethanol can complex with amylose and the linear exterior branches of amylopectin to prevent retrogradation (Erlander and Erlander 1969).

Sugars and Other Solutes

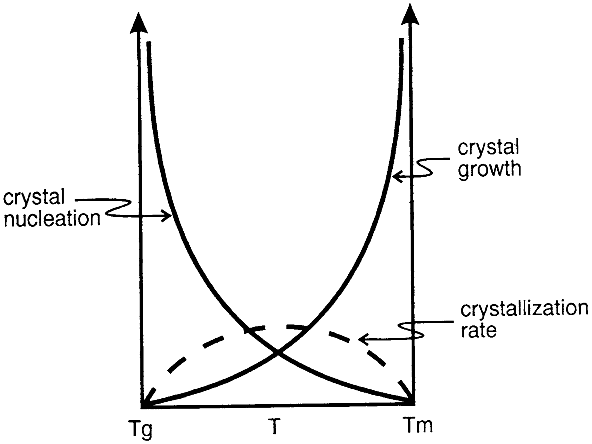
Sugars are also known to function as anti-staling ingredients in starch-based baked goods (Cairnes et al. 1991). I’Anson et al. (1990) investigated the effect of sucrose, glucose and ribose on the retrogradation of wheat starch gels at the nominal starch:sugar:water ratio of 1:1:1. Their findings suggest that the effectiveness of these sugars in reducing firmness and crystallinity follows the order ribose > sucrose > glucose. They also reported that for the level of added ribose no retrogradation or crystallinity was detected. The exact mechanism by which sugars suppress the crystallization of starch is not yet fully understood. It has been suggested, however, that sugars locally increase the glass transition temperature (T_g) and thereby dramatically reduce diffusion of polymer molecules to a crystal nucleus (I’Anson et al. 1990). Levine and Slade (1990) have proposed that sugars exert an anti-staling influence by raising the glass transition temperature of the amorphous amylose matrix, thus suppressing the re-crystallization of amylopectin. Increasing salt levels from 0 to about 2–3 % has been reported to decrease the firming rate of bread crumb (Maga 1975) but with the current emphasis on reducing salt levels in bread the potential effect of salt on bread staling is becoming more limited.

Freezing of Bread

Deep freezing can be used to prevent the process of staling and inhibit microbiological activity in bread. However, the freezing of bread is not simply a matter of storing loaves in a standard freezer. Such storage will certainly stop the process of starch re-crystallization, but if the maximum benefit is to be achieved it must be taken into account that after thawing, staling resumes and appears to proceed at a faster rate than in unfrozen loaves. In addition, during the freezing and thawing process the bread passes twice through the temperature range at which it stales fastest.

Avrami’s theory of phase change kinetics (1940, 1941) can be represented by an equation which was used by Cornford et al. (1964) to study the relationship between the elastic modulus of bread crumb and its storage time and temperature. They demonstrated that the relative rate of increase in the limiting modulus became greater as storage temperatures were lowered towards the freezing point. Bread stales more rapidly in the refrigerator than at ambient temperatures, but can be stored indefinitely in the deep freeze. The fact that the staling process gets faster as the temperature is reduced can be explained by polymer theories of re-crystallization which

Fig. 10.5 Crystallization kinetics of partially crystalline polymers (source: Morris 1990)



apply to partially crystalline polymers such as starch. This is due to the fact that there are actually two separate events that go to make up the process of crystallization in polymer systems such as gelatinized starch systems. The first of these two events is nucleation and the second crystal growth or propagation. These polymer theories suggest that crystal nucleation is favoured at lower temperatures but that crystal growth is favoured when the polymer chains are more mobile and form double helixes (Fig. 10.5).

Nucleation is the coming together of two or more polymer chains in the right arrangement to form a nucleus for subsequent crystal growth. Because the polymer chains are always moving, not all encounters lead to proper nucleation; the chains rebound or unwind again. In general, the number of successful nucleations increases as the temperature decreases. However, for crystal growth or propagation to occur, the polymers must be sufficiently mobile for the double helixes to aggregate or pack together into the crystallites. This mobility will increase with increasing temperature, so the rate of the propagation process also increases with increasing temperature.

So we can conclude that the rates at which optimum nucleation and growth occurs are different. The net result is that as the temperature of the product is reduced towards its glass transition temperature the rate of the overall crystallization process increases to a maximum, then falls. At storage temperatures below 0 °C (32 °F), the most important single parameter which determines the storage stability potential of a food product is its glass transition temperature. It was not until the 1980s that food scientists recognized the importance of the glass transition temperature in food systems and used it to predict product properties, quality and stability. Levine and Slade (1988) introduced the idea that foods could achieve mechanical stability if the freeze-concentrated, unfrozen water fraction is in a glassy state. For maximum storage stability, the product must be stored at a temperature that is below its glass transition temperature, T_g (Levine and Slade 1990). When products are stored below their T_g, they are known to have achieved the glassy state form. Once in the glassy state it is known that polymers, such as starch, are immobilized and that reactions and movement of solutes, such as sugar, and plasticizers, such as water, within their matrix are extremely slow. Bread stored below its T_g does not stale. Levine and Slade (1990) indicated that frozen storage stability is controlled by the temperature difference between the freezer temperature and the glass transition temperature.

The changes in the molecular motion of polymer chains from a glassy (rigid) state to a rubbery (flexible) state also depend on the amount of water in the system (Slade and Levine 1991). Breads with moisture contents of around 40 % after baking have their starch and proteins in the rubbery state above T_g and at ambient temperatures. In bread, the T_g is at −7 to −9 °C (20–16 °F), below which the staling process is inhibited. For temperatures above T_g and below the crystal melting temperature of starch, the material is 'rubbery' and sufficient motion of the polymer occurs, allowing crystallization. Under these circumstances, bread stored at, say, 21 °C (70 °F) is considerably above the glass transition temperature of the system, and would be expected to stale.

The freezing of bread can be achieved in a variety of ways. Cold air blown over the product is the commonest way. The air temperature and the air velocity will affect the rate of heat removal or freezing rates. The effect of freezing rates on bread crumb quality is related mainly to ice crystal formation. With respect to crystal formation upon freezing, slow freezing favours the formation of larger ice crystals, while fast freezing favours the formation of small ice crystals. Crystal growth is one of the factors which could affect the storage life of frozen bread, since ice crystals grow in size during storage and cause crumb weakening by damaging cell walls and disrupting internal structures to the point where the thawed product is quite unlike the original in texture and eating quality. More importantly, freezing rates control the amount of unfrozen water in the matrix. With rapid freezing, there is an increased frequency of ice crystal nucleation. This has a significant effect on the glass transition temperature of the product. Faster removal of heat enables the product to achieve a glassy state at a higher temperature, thus improving its frozen storage stability (George 1993).

It is important, therefore, to reduce the product temperature below its T_g as quickly as possible. With small-sized fermented goods, such as bread rolls, this can be achieved even in a common storage freezer unit with its limited air movement, provided the unit is not overloaded. With pan bread, such as 400 and 800 g pan loaves, blast freezing is necessary in order to achieve an adequately fast freezing rate and to prevent excessive staling during the initial freezing. Dehydration of the loaves is likely to occur with prolonged frozen storage time. This arises from the low humidity of the frozen air and can be avoided by adequate wrapping of the products in low-moisture permeability film and close packing of the frozen loaves in the freezer. During thawing, however, loaves should be well spaced out to promote maximum air movement around them and maximum rate of heat transfer into the cold product. Partial defrosting and re-freezing of baked breads should be avoided since they may give rise to the phenomenon referred to as 'freezer burn'—the formation of white opaque patches in the crumb or on the crust of baked products (Cauvain and Young 2008).

Even when held in a freezer the can be moisture movement in the stored product. With prolonged frozen storage it is not unusual to see ice crystals forming in the pack (Cauvain and Young 2008). These ice crystal represent water which has sublimed from the frozen bread product during storage to condense in the atmosphere within the pack. Without being wrapped bread products will simply dehydrate with increasing storage time. 'Shelling' of the crust of part- or fully baked products may occur during frozen storage or on defrosting. Crusty products are a particular problem (Cauvain and Young 2009) because the differences in moisture content between crust and crumb exacerbate the effect of differential freezing arising from the poor conductivity of baked products.

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Chapter 11
Principles of Dough Formation

Introduction

The first, basic step in breadmaking is combining water with wheat flour and kneading (imparting mechanical energy to) the mixture to form an elastic dough (Bushuk, 1985; Hoseney, 1985). Flour from wheat, rather than from other cereal grains, is used because wheat storage proteins have unique properties; no other cereal storage protein possesses the ability to form a visco–elastic dough when wetted and kneaded. A full explanation at the molecular level for this uniqueness still eludes researchers.

The events that occur when gluten proteins are hydrated and worked are also elusive. Part of the obscurity is due to the complexity of the system. The basic properties of dough are established by the characteristics of the storage (gluten) proteins in the flour. These characteristics, however, are modified by other flour components, both soluble and insoluble, as well as the additional ingredients added to dough. In studying dough formation we are limited to observing physical events on a macro scale or at the supra-molecular level. Numerous techniques that study molecular properties have been applied to dough including; X-ray analysis, nuclear magnetic resonance (NMR), differential scanning calorimetry (DSC), electron spin resonance spectrophotometry (ESR) and scanning electron microscopy (SEM). The interpretation of the results, however, is always complicated by the complexity of the system. X-ray analysis, for example, led to a model of the dough matrix (Grosskreutz, 1961) that included gluten proteins, phospholipids and solid (starch) contributions, but there is no way to confirm independently the accuracy of that model. While these techniques each help us clarify certain aspects of dough structure, the concepts that will be set forth in this chapter remain speculative to a significant degree. This fact must be kept firmly in mind while reading this or any other publication on dough formation.

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The macro-properties of dough change with time. At the end of the mixing process (Chap. 4) the dough has certain visco-elastic characteristics that are considered optimum for subsequent processing. The resting period (floor-time) changes these properties and makes the dough more pliable (relaxed). Dividing and rounding reverses this to some extent and the dough appears more elastic (less relaxed). An intermediate proof period decreases the elasticity, allowing good moulding into the shape of a loaf. During proofing the characteristics are further modified, not only by relaxation but also by changes in matrix composition from the products of fermentation (ethanol, carbon dioxide), by the action of additives (oxidants and enzymes) and possibly by the action of native flour proteases. Again, our understanding of the molecular alterations resulting in these modifications in dough properties is rudimentary at best.

Governing all our discussions about dough formation (and the breadmaking process) is the fact that the ultimate criterion of 'good' or 'poor' structures and processes is the final product—a good loaf of bread. The two main contributors to bread quality are volume (stability in the prover or proof-box and good oven spring) and a fine, silky crumb. These desirable outcomes depend, obviously, on certain optimum properties in the dough matrix. Two characteristics define 'good' dough:

- The ability to retain gas (carbon dioxide), generated during fermentation (proofing), in the form of numerous small gas cells;
- A proper balance of viscous flow and elastic strength so that the loaf can expand adequately during proofing and the early stages of baking, yet retain its rounded form.

Gluten (hydrated wheat storage protein) is the component of dough that determines how well these requirements are met. While other flour components affect gluten functionality, and mechanical energy input during mixing is crucial to developing the proper characteristics, it is still the physicochemical nature of gluten proteins with which we will be mainly concerned in this discussion of dough formation.

Flour and Dough Components

Wheat flour components (dry basis) can be classified into seven groups:

1. Starch;
2. Storage (gluten-forming) proteins;
3. Non-starch polysaccharides (pentosans);
4. Lipids;
5. Water-soluble proteins;
6. Inorganic compounds (ash).
7. Celluloses associated with bran layers, their level is limited in white flour but is higher in wholemeal flours.

Starch is relatively inert during dough mixing, but plays a role as a ‘filler’ that contributes to increased dough visco-elasticity. (Starch, of course, has a critical influence during the baking process, when it gelatinizes, and during subsequent storage, when retrogradation accounts for the major part of bread staling (see Chap. 10.) Endogenous inorganic materials are relatively unimportant in dough formation, although added salt strongly influences dough properties. The other five component groups listed are actively involved in dough formation during mixing and subsequent processing.

Starch

Starch represents by far the largest portion of flour, making up about 65 % of ordinary flour (14 % moisture basis). Wheat starch comprises about 23 % amylose and 73 % amylopectin (thus the two species represent 15 and 50 % of the flour weight, respectively). Amylose is a linear chain of α-1,4 linked glucose units, with a molecular weight in the range of 100,000 Da, while amylopectin is a highly branched structure, with an estimated molecular weight in the range of 20,000,000 Da (Fig. 11.1). Native starch exists as granules and has a high degree of crystallinity, evidenced by birefringence (the ‘Maltese cross’ seen when it is examined with a polarizing microscope). These granules are relatively inert during mixing but influence dough elasticity by their presence in the total matrix. In hard wheat flour as much as 15 % of the starch granules (10 % of the flour weight) are ‘damaged’, that is, they have been deformed during milling and contain cracks and fissures. Damaged starch granules absorb about four times as much water as intact granules, and increase dough water absorption (see below and Chap. 12). Also, damaged starch is much more susceptible to the action of α-amylase than is intact starch, a fact that enters into dough property modification during the proofing stage of processing.

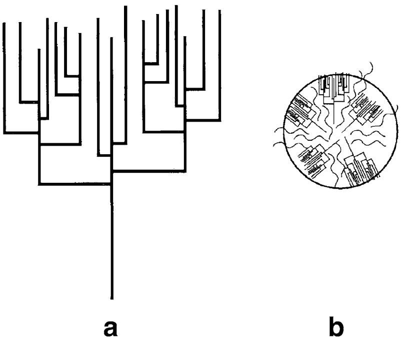


Fig. 11.1 (**a**) Amylopectin, (**b**) a starch granule

Gluten

The storage protein found in flour is not, strictly speaking, gluten; that term designates the hydrated glutelins (glutenins) and prolamines (gliadins) formed when a dough is mixed. However, for convenience in this discussion the anhydrous storage protein of wheat endosperm will be called gluten (as the term is commonly used). Of the total protein in wheat flour, about one-sixth is soluble protein (albumins and globulins), falling into group 5 in the list above. Thus a flour having 12 % protein contains only about 10 % gluten-forming proteins. The molecular characteristics of these gluten proteins will be examined in more detail below.

Pentosans

Non-starch polysaccharides represent only about 2–2.5 % of flour (Michniewicz, Biliaderis, & Bushuk, 1990), but have a disproportionate influence on dough properties. They are sometimes called hemicelluloses because they constitute part of the cell wall materials (formed in conjunction with cellulose) in the seed, made by the plant as the wheat berry is synthesized and ripening. More often the name pentosan is used because approximately 80 % of the sugars present are the pentoses D-xylose and D-arabinose. The pentosans are a heterogeneous group of macromolecules, but the preponderant backbone structure is a xylan, a chain of β-1,4 linked D-xylose units. Various other sugars are attached to this chain by α-1,3 linkages; the major side chain sugar is arabinose, but small amounts of glucose, fructose and mannose are also found. Besides the xylans, a significant amount of arabinogalactan (polygalactose chain with arabinose side chains) is present in the water-soluble portion.

About 65 % of wheat flour pentosans are water-insoluble (WI) pentosans (Michniewicz et al., 1990); these are almost exclusively xylans. The water-soluble (WS) pentosans are approximately half arabinoxylans and half arabinogalactans. Pentosans are gums; they absorb several times their weight in water and form highly viscous solutions. This is especially important in rye flour (Chap. 13), where the pentosan content may be as high as 10 %; the viscosity that allows rye flour to form a dough is due almost exclusively to the pentosans. The water-absorbing property of pentosans is influential in wheat flour doughs (see below) and the viscosity due to the WS pentosans influences the visco-elastic behavior of dough.

Flour pentosans form gels when treated with certain oxidants (Geissman & Neukom, 1973). The mechanism involves ferulic acid, an α,β-unsaturated aromatic carboxylic acid that is esterified to arabinoxylans (Fig. 11.2). Oxidants that generate free radicals, for example hydrogen peroxide, promote cross-linking between ferulic acid residues on adjacent polymer chains and lead to gelation of suspensions of both WI and WS pentosans. The formation of covalent linkages with gluten proteins has been postulated (Neukom & Markwalder, 1978), via reaction between ferulic acid and tyrosine side chains of the protein (Fig. 11.3). Sulfhydryl compounds react with α,β unsaturated aromatic acids. ^{14}C-tagged cysteine binds to WS pentosans

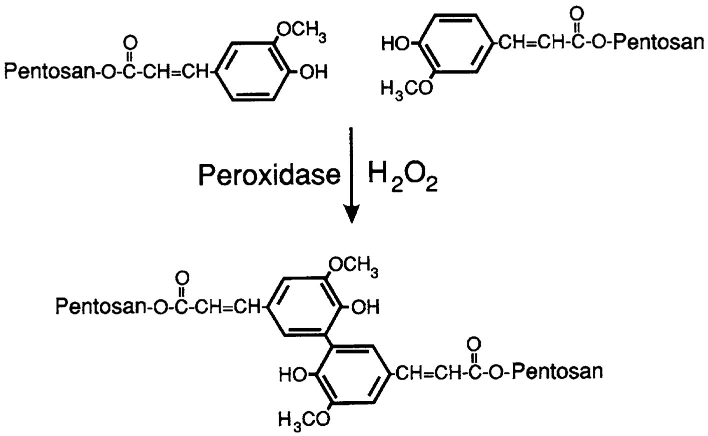


Fig. 11.2 Oxidative crosslinking of ferulic acid in flour pentosans

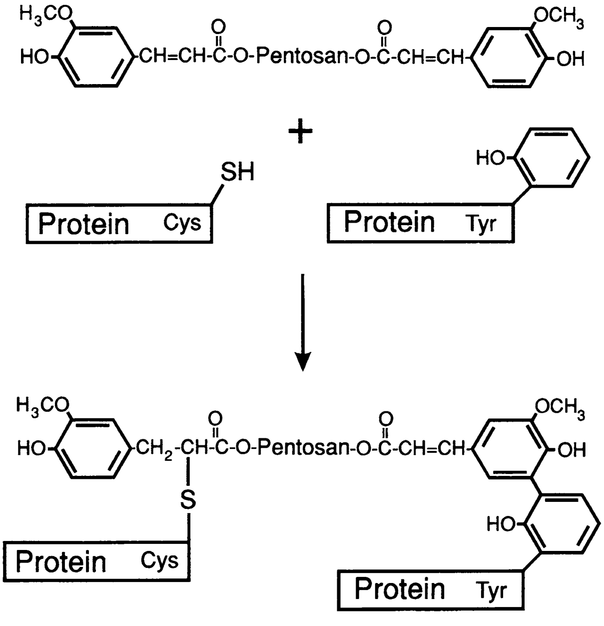


Fig. 11.3 Reactions of water-soluble pentosans with dough proteins. *Left*, addition of –SH to ferulic acid. *Right*, ferulic acid linking to tyrosine

(Sidhu, Hoseney, Faubion, & Nordin, 1980b), presumably through addition of the—SH group across the activated double bond. Cysteine inhibits the oxidative gelation of pentosans (Hoseney & Faubion, 1981). Carboxylic acids with an activated double bond (e.g. fumaric acid and cinnamic acids) drastically reduce the mixing stability of doughs (Hoseney & Faubion, 1981). These facts have been interpreted to mean that during normal dough mixing feruloyl moieties attached to pentosans are attached to gluten proteins via addition of sulfhydryl groups across the activated double bond, generating cross-links and enhancing dough elasticity (Fig. 11.3).

Lipids

Wheat flour contains about 2.5 % lipids. Of this, about 1.0 % is non-polar lipids (triglycerides, diglycerides, free fatty acids and sterol esters). The two main groups of polar lipids are galactosyl glycerides (0.6 %) and phospholipids (0.9 %). During mixing, both classes of lipids are complexed with gluten and become relatively unextractable with any of the usual solvents (Daniels, Wendy-Richmond, Russell-Eggitt, & Coppock, 1976; Wootton, 1976; DeStefanis, Ponte, Chung, & Ruzza, 1977). Grosskreutz (1961) interpreted his X-ray spacings to indicate the presence of bimolecular layers of polar lipids in the gluten complex, and polar lipids have been proposed as adhesive agents between starch granules and gluten protein in several other models (Chung, 1986).

Flour lipids appear to have little effect on mixing requirements; the mixogram is identical for control and defatted flours (Schroeder & Hoseney, 1978). On the other hand, the addition of anionic surfactants such as sodium dodecyl sulfate strengthens the dough and increases mixing time (Danno & Hoseney, 1982). While these are not flour components, the effect offers further insight into the nature of the gluten complex (and how mechanical mixing modifies it) and will be discussed in more detail below. Lipids have a major influence on baking performance of bread (Wilde, 2012), especially with respect to oven spring (loaf volume) and the keeping quality of the finished product. Protein-lipid interactions are formed in bread dough though their role in the stability of bread dough is not always clear with both beneficial and negative effects being observed depending on the concentration and nature of the lipid itself. With the increased use of lipase enzymes (Kornbrust, Forman, & Matveeva, 2012) the contribution of flour lipids to bread quality is once again attracting attention.

Water-Soluble Proteins

The water-soluble fraction of flour (approximately 2–3 % of total flour weight) contains albumins and globulins as well as WS pentosans. The proteins include enzymes, enzyme inhibitors, lipoproteins, lectins, and globulins of unknown function. It is reported that two-dimensional electrophoresis shows over 300 components. These undoubtedly have some biological function in the seed, relating to its primary role as the progenitor of the next wheat plant. The only clearly identified role played by any of these compounds in baking is the action of β-amylase on starch, generating maltose which serves as a fermentable sugar for yeast during proofing of lean doughs.

Reconstitution studies with fractionated flour components show that the water-soluble fraction plays a role in the breakdown of over-mixed dough (Schroeder & Hoseney, 1978). A mixogram of only the gluten and starch fractions showed a long mixing time with extremely long mixing tolerance; when the water-soluble fraction was also included the mixogram resembled that of the control (un-fractionated) flour. The fraction was dialyzed (removing low molecular weight materials) and then heated (denaturing proteins). The remaining soluble material (presumably mainly WS pentosans), when added back to the gluten plus starch fractions, gave a mixogram similar to that of the control, i.e. mixing to a peak followed by relatively rapid breakdown.

Ash

White wheat flour contains about 0.5 % ash which is a measure of the level of bran that is present (see Chap. 12), in wholemeal flour the levels are significantly higher. The inorganic material which comprises ash no significant influence on dough formation or subsequent bread quality. The inorganic materials which comprise ash are closely associated with the bran layers in wheat which is why their measurement is so important to the miller (Cauvain, 2009) and baker. In the context of dough formation and stability, the presence of bran particles should be seen as a negative in that the presence of the bran particles disrupts the formation of a cohesive network and contributes to instability during the gas bubble coalescence processes which take place in the later stages of proof and the early stages on baking. The particle size of the bran can have a significant impact on the gas retention ability of the dough with smaller bran particles having a large negative impact than large. In part this account for the fact that stoneground wholemeal flours often deliver lower bread volume than those based on the reconstitution from roller-ground fractions (Cauvain & Young, 2001). The negative impact on bread particles on dough gas retention can often be overcome by the addition of other functional ingredients which deliver improved gas retention, e.g. fat (Chap. 3).

Flour Components and Water Absorption

An important factor in commercial bread dough production is the proper water to flour ratio (Cauvain & Young, 2008). In common usage this ratio is called ‘absorption’, and expressed as a percentage of the flour mass. The adjective ‘proper’ differs depending upon the kind of dough being made (absorption is much lower for a bagel dough than for a white pan bread dough) and the method used in its measurement (Farinograph absorption can be 2–4 % lower than operational absorption). Operational (or baking) absorption, of course, means the water to flour ratio that results in a dough having the handling (machinability), proofing and baking (loaf volume), and finished product (appearance, eating quality) characteristics necessary to give the desired baked food (bread). As stated above and discussed in Chap. 1, the criterion of ‘good’ or ‘poor’ is determined by the final product and the consumer. The contribution of various flour components to absorption has usually been made using some sort of instrumental measurement, with the instrument defining ‘correct’ absorption. This is most often the Brabender Farinograph (Chap. 12), which records mechanical resistance as a simple mixture of flour and water is kneaded. Farinograph absorption is the water to flour ratio that results in a recorder trace which, at its maximum, is centred on the 500 (or 600 in the UK) Brabender units line. This is generally lower than baking absorption—the water to flour ratio, determined by an experienced mixer operator that gives optimum dough handling and final product qualities. The absorption numbers that are presented here must be understood as representing the relative water uptake by the various components, and not an attempt to allow precise calculation of baking absorption for a given flour based upon analytical data.

Four white flour components absorb water; protein, native starch, damaged starch and pentosans. The relative absorptions (in grams of water per gram of component) are given in Table 11.1. Using analytical data (typical for a hard red spring wheat flour) shown in column 3, an absorption of 68.4 % is calculated (total of column 4), which is reasonable for such a flour.

Both soluble and insoluble (gluten) proteins absorb water (Greer & Steward, 1959; Bushuk, 1966). We might expect that absorption by the insoluble gluten proteins would have more effect on dough rheology than solution of the soluble proteins, but the specific evidence for such a conclusion is somewhat indirect. The greater influence of gluten proteins on baking absorption is highlighted in a study by Tipples et al. (1978). They measured total protein, wet gluten, gluten ‘quality’ (wet gluten quantity divided by total protein), damaged starch and pentosan contents of flours from a number of milling streams of Canadian hard red spring wheat. They also measured Farinograph absorption and baking absorption (for several different baking protocols) of the flours. The most important predictor of Farinograph absorption was damaged starch content; inclusion of total protein improved the prediction equation significantly, but including the other factors produced no further improvement (i.e. no increase in r^2). Of the five baking tests they used, the one most like commercial (North American) production methods was the remix test that included 0.3 % malt. This test is similar to the standard American Association of Cereal Chemists International (AACCI) baking test, with a long (nearly 3 h) bulk

Table 11.1 Influence of flour components on absorption

Component	Water per g component (g)	Amount per 100 g flour (g)	Absorption per 100 g flour
Protein	1.3	12	15.6
Intact starch	0.4	57	22.8
Damaged starch	2.0	8	16.0
Pentosans	7	2	14.0

fermentation, but the dough is then remixed before being moulded and panned. The most important single factor in predicting baking absorption was gluten quality. Adding simple protein level as a prediction factor significantly increased reliability (r^2), but the other factors (damaged starch and pentosan content) were not statistically significant.

Native starch granules are relatively impermeable to water. This may be due in part to the lipids and protein found on the surface of the granules, probably derived from the cell wall of the amyloplasts present in the ripening wheat berry (Greenwood, 1976). While native starch is the largest single contributor to absorption, this is due to its preponderance in flour. During baking, of course, when these granules swell and gelatinize, the contents become readily hydratable and are probably the main water-binding species in baked bread.

Most damaged starch is formed during milling (though amylase action in sprouted grain can also cause starch damage). During the process of reducing chunks of endosperm from the break rolls to flour on the reduction rolls, the particles are subjected to extreme pressure. The granules are somewhat elastic and return to their original shape after the pressure is relieved, but some granules are left with cracks and fissures. These represent spots where water can readily penetrate to the interior of the granule and interact with the amorphous regions found there. More pressure at the reduction rolls is needed to break up hard wheat endosperm than for soft wheat; hence hard wheat flours typically have a higher damaged starch content (6–12 %) than soft wheat flours (2–4 %). These cracks also represent points of susceptibility to amylase action, in contrast to intact starch granules which are resistant to amylolytic attack under ordinary conditions. Digestion by amylases in dough releases maltose, which can be fermented by yeast, as discussed in Chap. 3. Also, during proofing digestion of damaged starch decreases its water-holding capability, releasing more water into the dough matrix and increasing pan flow. Significant amylolytic activity requires some period of time, and is not a factor during the relatively short time involved in dough formation.

Studies on the water-absorbing capabilities of pentosans give rather varied results. Kim and D'Appolonia (1977) added isolated pentosans to flour and measured the change in Farinograph absorption. The addition of 1 % WS pentosan increased absorption by 4.4 %, while 1 % WI pentosan increased absorption by 9.9 %. Michniewicz et al. (1990) added WI pentosan to various hard wheat flours at different levels, and measured the changes in Farinograph absorption. They found increases in absorption ranging from 3.2 to 5.6 g of water per gram of pentosan; the increment was smaller when the intrinsic baking quality of the test flour was better. Patil et al. (1976) used flour fractionation and reconstitution studies to explore the effect of flour water solubles and WS pentosan fractions on absorption, mixing time and loaf volume. They found essentially no effect of WS pentosan on baking absorption (and a small, variable effect on mixing times). Based on published reports, a median value of 7 g of water absorbed per gram of flour pentosans was chosen for inclusion in Table 11.1.

Bran is of course a mixture of many different wheat polysaccharides, some of which are discussed above. In practical terms it is important to recognise that the level of bran also impacts the water absorption capacity of flours not just in absolute terms but also with respect to the rate at which water is taken up during doughmaking. The physical structure of bran particles commonly means that they are slow to hydrate. This has practical implications for dough processing in that high-bran doughs (e.g. based on wholemeal) may appear to have a satisfactory consistency on leaving the mixer but as the water is slowly absorbed into the bran the doughs become firmer and this may have an adverse behaviour on the moulding and shaping processes which follow dough mixing. In some cases a short pre-hydration phase may be incorporated at the start of the mixing process typically this comprises mixing the ingredients for a short length of time at a slower speed prior to full development of the dough.

Wheat Gluten Proteins

Wheat proteins have occupied a central position in protein studies since early times. Gluten was first recognized as the rubbery component of wheat flour in 1729 (Bailey, 1941), although at that early stage it was not called protein (the term had not yet been coined). The common method of characterizing proteins based on their solubility was developed using wheat proteins (Osborne, 1907). According to Osborne's scheme, proteins were divided into four groups:

- Albumins, soluble in distilled water;
- Globulins, soluble in dilute salt solutions;
- Prolamines, soluble in 70 % aqueous ethanol;
- Glutelins, soluble in dilute acid.

Gluten proteins are members of the latter two groups.

Amino Acid Composition

Wheat gluten proteins are anomalous, even compared to other cereal storage proteins, in their amino acid make-up (Kasarda, 1989). About one-third of the residues are glutamyl residues, which are almost entirely in the form of glutamine (the amide of the side chain carboxyl group). The amide, a non-ionizing group, readily forms hydrogen bonds with electron donors (other amides and water molecules). The content of basic amino acid residues (arginine, lysine and histidine) is relatively low, and the amount of carboxylic acid residues (aspartic and glutamic acid) is even lower. As a result the proteins have a rather low surface charge density, even at pH values somewhat removed from the isoelectric point. Since the charge repulsion between molecules is low the protein chains can approach each other and interact (form hydrogen bonds) in the aqueous dough matrix. The addition of sodium chloride further suppresses charge repulsion, increasing molecular interaction.

Gluten also contains a higher level (about 14 % of the residues) of proline than is usual in proteins. This amino acid favours the formation of β-sheets (Belton, 2012) and similar structures that are thought to be responsible for some of the elastic characteristics of gluten (see discussion below). While the content of hydrophobic amino acids is not unusual, the lack of ionic character makes hydrophobic interactions between protein chains possible. The hydrophobicity of gluten proteins has been demonstrated experimentally by chromatography of acid-solubilized gluten on hydrophobic gel media such as phenyl-sepharose (Chung & Pomeranz, 1979). These authors examined gluten from two flours having different baking properties, and found that glutenin from the good-baking flour was more strongly absorbed to the gel than the glutenin from the poor-baking flour. Surprisingly, the relationship was reversed for gliadin; that from the poor-baking flour was bound somewhat more strongly than gliadin from the good-baking flour. Kaczkowski et al. (1990), on the other hand, found gliadin from good-baking wheat to be slightly more hydrophobic than gliadin from wheat of medium-baking quality. They used binding capacity for sodium dodecyl sulphate as their criterion of hydrophobicity, a difference in technique that might account for the discordant results.

Gliadin

Actually a heterogeneous group of prolamines, more than 70 different gliadin species have been identified, using chromatography and electrophoresis. They are rather hydrophobic, hence their insolubility in water or salt solutions, but can be divided into groups based upon their degree of hydrophobicity. More hydrophobic gliadins (the γ-gliadins) increase bread loaf volume, while gliadins from the more hydrophilic end of the spectrum (θ-gliadins) decrease loaf volume (van Lonkhuijsen, Hamer, & Schreuder, 1992; Weegels, Marseille, de Jasger, & Hamer, 1990). Gliadin proteins are relatively small, with molecular weights in the range 30,000–100,000 Da. They are single-chain proteins (i.e. no cross-links between chains) and disulphide bonds as occur are all intra-molecular (Fig. 11.4a). Concentrated solutions of isolated gliadin are highly viscous, with little measurable elasticity.

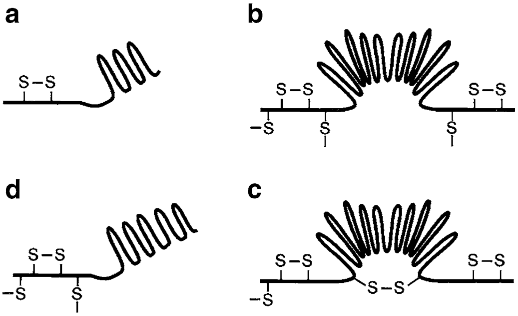


Fig. 11.4 Schematic depiction of gluten proteins. (**a**) Gliadin, (**b**) HMW glutenin subunit, showing possible action of the β spirals as 'molecular spring', (**c**) HMW glutenin subunit, showing disulphide bond preventing extension of the β spirals, (**d**) LMW glutenin subunit

Glutenin

Glutenin is the type example of Osborne's glutelins. Like gliadin it is quite hydrophobic (its amino acid composition is similar to that of gliadin) but it has a very different molecular structure; glutenin is a polymeric protein. The average molecular weight of native glutenin is stated to be about 3×10^6 Da, a number that is highly approximate and serves only to characterize the wide molecular weight distribution of glutenin (Kasarda, 1989). Polymerization takes place via intermolecular disulphide bonds. Reduction of these bonds with a reagent such as dithiothreitol (DTT) frees the basic glutenin subunits, which can be separated using SDS-PAGE (electrophoresis in a polyacrylamide gel in the presence of a high concentration of sodium dodecyl sulphate, a technique that separates proteins on the basis of their molecular weights). Two groups of subunits are identified. High molecular weight glutenin subunits (HMW-GS) have apparent molecular weights in the range 80,000–120,000 Da, while the molecular weights of low molecular weight glutenin subunits (LMW-GS) are about 40,000–55,000 Da. The molar ratio of LMW-GS to HMW-GS is 2:1 or higher; the amounts of the two kinds of subunits are roughly equal on a weight basis.

The molecular architecture of glutenin subunits is unusual (Fig. 11.4). In HMW subunits cysteine is concentrated in the regions near each end of the chain, with a long stretch of other amino acids between these two ends. The cysteine residues are involved in both intra- and inter-molecular disulphide bond formations. LMW subunits have a similar concentration of cysteine residue, but at only one end of the chain (Fig. 11.4d). Thus, both ends of the HMW protein can enter into polymerization reactions, while only one end of the LMW protein can react this way. The interior regions of both species, but the HMW subunits in particular, are postulated to form β-turn spirals, which in turn can fold into a helical sheet structure that can possibly be likened to a coil spring (Fig. 11.4b). This is only a hypothesis, but it is an attractive one that could account for the elastic nature of glutenin. An intramolecular disulphide bond can restrain this 'spring' (Fig. 11.4c); this bond can be broken during mixing (see below) to 'develop' the gluten structure. Isolated glutenin, when re-hydrated, forms an elastic, rubbery mass that has almost no viscous flow characteristics.

Numerous proposals have been put forward for the structure of glutenin polymers in dough (Fig. 11.5). Unfortunately, because glutenin is such an intractable protein to examine, these must of necessity be considered speculative. Graveland et al. (1985) postulated a basic 'building block' of three glutenin subunits linked through disulphide bonds (glutenin IIIa) and a tetramer of this basic structure (glutenin IIIb). These react with linear proteins having two or more reactive sulphydryl sites, to form a larger molecule called glutenin II. Glutenin I is a highly polymerized, insoluble protein which is thought to be the glutenin protein present in wheat flour. It is partially depolymerized during mixing and reforms during the resting stage of dough processing. Gao et al. (1992) examined the effects of small amounts of DTT on dough consistency in the Farinograph, and arrived at a slightly different model. They also postulate a subunit structure similar to Graveland's, but specify both

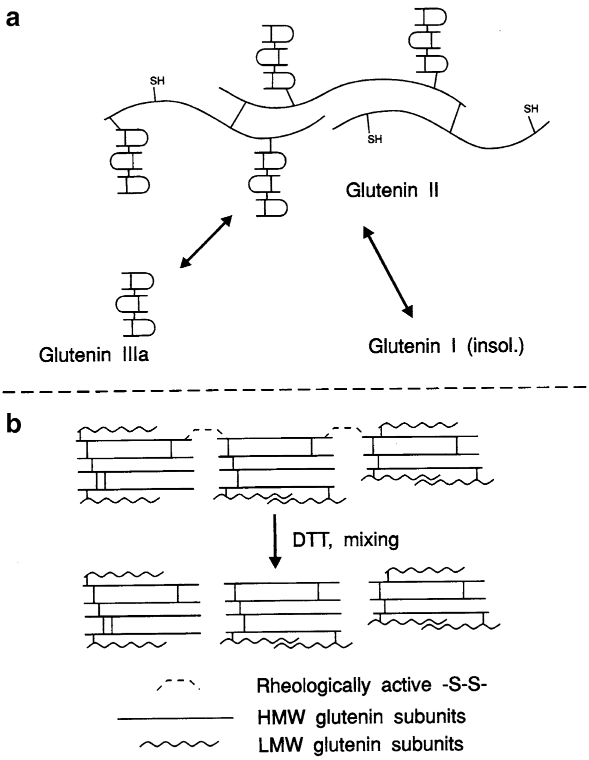


Fig. 11.5 Two models of glutenin structure in dough. (**a**) Adapted from Graveland, Bosveld, Lichtendonk et al. (1985), (**b**) adapted from Gao, Ng, and Bushuk (1992)

HMW and LMW subunits in their 'building block'. In their work DTT reduction of a small portion of disulphide bonds produced the maximum decrease in consistency; they called these 'rheologically effective —S—S—'. Jones et al. (1974) used a similar approach (a change in Farinograph consistency in the presence of small amounts of DTT) to conclude that only about 3 % of the disulphide groups in flour affect the rate of dough development, and about 12 % of the disulphide groups are involved in mixing resistance. The best current picture of glutenin is that it is a large linear polymer, and interactions between glutenin chains in dough is through non-covalent forces, namely hydrogen and hydrophobic bonds (Ewart, 1977).

Stages in Dough Formation

The word 'dough' connotes a semi-solid mass that resists mixing. In a recording mixer such as the Mixograph, a dough in the mixing bowl gives enhanced (and variable) resistance as the mixing head rotates, while a batter (a semi-liquid mass) causes low resistance with little variability (narrow band width). The progression from a simple mixture of water and flour to a dough correlates with an increased

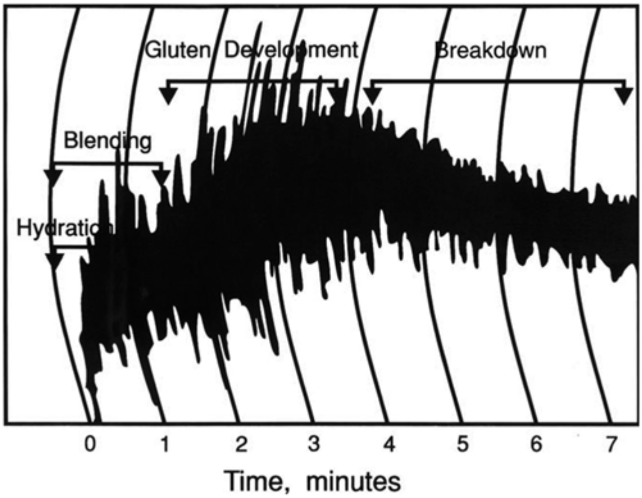


Fig. 11.6 (**a**) Mixograph trace, indicating the four main stages of dough formation

resistance to mixing, however that may be recorded. A Mixograph is just as much a mixer as any large commercial dough mixing machine, and the trace can be easily translated into consistency changes during dough mixing. In Fig. 11.6 a typical Mixograph trace shows the various stages of dough formation: hydration, blending, gluten development and breakdown. These same stages can be observed in a commercial horizontal mixer (Pyler, 1988). Bakers in the USA refer to them as the ‘pickup stage’ (Pyler, 1988, Fig. 14.3), ‘cleanup stage’ (Pyler Fig. 14.4), ‘development’ (Pyler Figs. 14.5–14.7) and ‘letdown’ and ‘breakdown’ (Pyler Figs. 14.8 and 14.9), respectively. Similar changes can be observed in most dough mixing and development systems in use around the world. An example of a mixing curve obtained from a Tweedy mixer use in CBP dough production is illustrated in Fig. 7.1 and shows how similar the shape of that curve is to that from a Mixograph or Farinograph despite the very different action of this type of mixer.

Hydration

In flour most of the protein exists as a flinty material. An analogy for the hydration of this protein is hydration of a bar of soap. If the soap is simply immersed in a bowl of water, the water slowly penetrates the outer layer of the bar. Rubbing the soap wipes off this soft, hydrated layer, and water proceeds to penetrate further into the soap. In the same way, the initial action of the mixer hastens the conversion of the flinty protein bodies into a soft, hydrated (but not truly dissolved) protein dispersion that is further modified during gluten development. Simultaneously the WI pentosans and damaged starch granules are absorbing water, and the water-soluble flour components (and added water-soluble ingredients such as salt and sugar) are dissolving.

The soap analogy is not strictly accurate. When water is brought into contact with flour particles and the process is observed under a microscope, the particles seem to explode; strands of protein are rapidly expelled into the aqueous phase (Bernardin & Kasarda, 1973). Movement of the cover glass stretches the protein strands, indicating their extensibility (Amend & Belitz, 1990). The rapid extrusion of protein fibres appears in part to be due to surface tension at the air–water–protein interface. Amend and Belitz (1990) submerged flour particles in acetone, which was then replaced by water. The particles swelled but no fibre formation was evident.

The input of mechanical energy is crucial to dough formation. A simple exercise demonstrates this fact. Blend cold wheat flour with powdered ice (in a 100:65 ratio) and then allow it to warm to room temperature. The result is a thick slurry that has no dough-like properties. When this slurry is stirred it rapidly increases in consistency, forming a soft (undeveloped) dough. Hydration alone is not sufficient to make a dough. Tkachuk and Hlynka (1968) substituted D_2O for water to show the importance of the formation of hydrogen bonds in dough. The mixing energy required to develop a dough using D_2O was much greater than that when water was used indicating that the hydrogen bonds formed with D_2O were significantly stronger.

Blending

Flour particles are agglomerates of starch granules embedded in a network of protein (Fig. 11.7). As the protein network is softened by hydration and agitated by mixing, the starch granules become less firmly attached to the protein, but nevertheless remain associated with the protein fibres (Fig. 11.8). Most of the starch can be removed by washing and kneading the dough (the basis for isolating wet gluten) but it cannot be totally removed. SEM photos of optimally mixed dough indicate that most of the starch is readily removable, but a small number of granules appear to have protein fibrils strongly attached to them (Amend & Belitz, 1990, Fig. 20). The actual strength of the starch–protein interactions has not, of course, been measured, but only inferred from observations such as those described. During this early stage of mixing all the ingredients of dough are being blended, to give a dough mass that

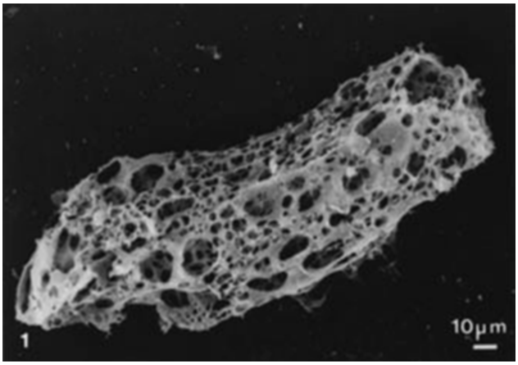


Fig. 11.7 Hydrated flour particle after starch is removed by enzymatic digestion, showing the protein framework (from Amend, 1995, by permission)

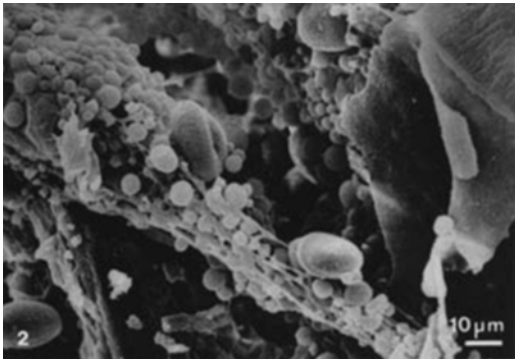


Fig. 11.8 Protein film and associated starch granules in a hydrated, stretched flour particle (from Amend, 1995, by permission)

is, at least at the millimetre scale, homogeneous. Lipids (flour and added lipids) are uniformly distributed and brought into contact with the protein fibres, and soluble materials are fully dissolved and distributed in the aqueous matrix.

Gluten Development

The pivotal step in forming a wheat-flour dough is the increase in consistency (increased resistance to mixing) that is generally called 'dough development'. During this stage of mixing, the flour–water mixture is converted from a thick, viscous slurry to a smooth visco-elastic mass, characterized by a dry, silky appearance (and feel) and the ability to be extended into a thin continuous membrane. The most important practical parameter is mixing time (which can be equated to total energy input, however, in this context the impact of mixing speed on the degree of dough development discussed in Chap. 2 should be noted), the time required to reach the peak consistency (maximum resistance) of the dough. Dough mixed to this point gives the maximum loaf volume, as compared with dough that is under-mixed or significantly over-mixed. It should be noted that in commercial practice mixing is usually extended slightly beyond the peak, giving a dough with better machinability in the subsequent moulding step, and one less likely to exhibit a 'wild shred' during baking. Data published by Millar and Tucker (2012) has also shown that maximum bread volume is achieved after mixing beyond an 'NIR optimum' for dough and that the finest cell structure that could be achieved in bread made by the CBP occurred sometime before the volume optimum. Such observations support the practical experience of bakers for a need to mix beyond peak dough resistance to deliver optimum bread quality.

The previous paragraphs describe (dough gluten) development on the macroscopic scale. Scanning electron microphotographs of gluten at various stages of development have been published. One such series is shown in Fig. 11.9 (Amend, 1995). At early stages (corresponding to the 'hydration' segment of Fig. 11.6) the

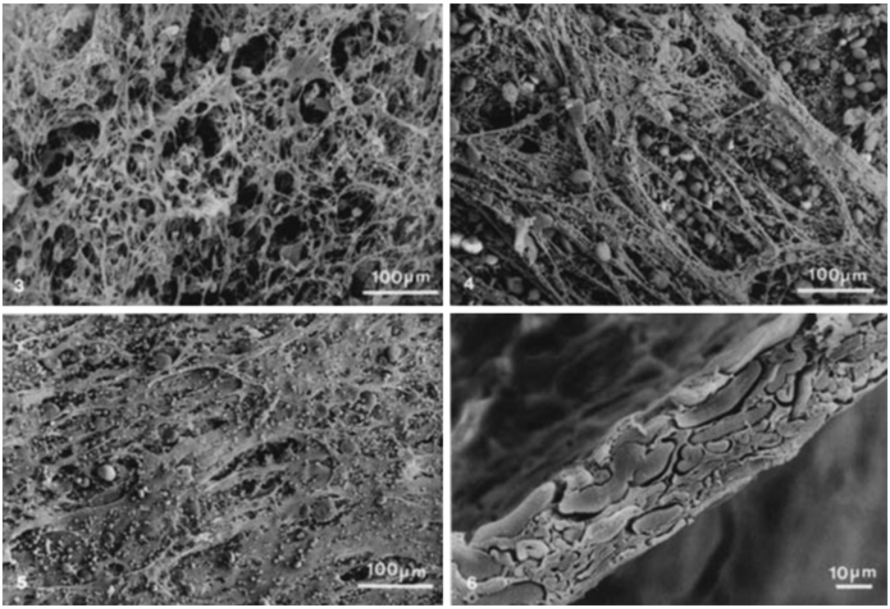


Fig. 11.9 Gluten network in dough at various stages of mixing. (**a**) Early in the process (at about the middle of the hydration stage), (**b**) partially mixed dough, (**c**) dough at maximum development stage (from Amend, 1995, by permission)

fibrils of hydrated protein adhere to each other, forming a rather coarse, random network of large strands (Fig. 11.9a). The action of the mixer stretches these strands, thinning them but also orienting them along the direction of the stretching action, allowing them to interact with each other (Fig. 11.9b). At the peak of consistency (Fig. 11.9c) the protein fibrils have been significantly reduced in diameter, and they appear to interact two-dimensionally, rather than just along the individual strand axes. In other words, at this stage the gluten appears able to form the continuous film, or gluten sheet, that is used by a baker (by hand-stretching a piece of dough) to evaluate completeness of mixing.

The crucial question, and one that continues to generate much research, is ‘What happens on the molecular level during dough mixing?’ The research is complicated by the complexity of the dough system, and the fact that the main species involved (glutenin) is a high molecular weight polymeric protein that is, to a large extent, insoluble. Nevertheless, progress towards the answer is being made.

It seems clear that mixing breaks the high molecular weight glutenin into smaller units, which then reform to some extent. Graveland et al. (1985 and references therein), for example, found that during short high-energy mixing the amount of glutenin having a lower molecular weight (less than 1 MDa) increased sharply, but then decreased again when the dough was allowed to rest. This is the basis for the model shown in Fig. 11.4a; the insoluble glutenin I (assumed to be the form in the dry endosperm) is depolymerized, perhaps down as far as the glutenin III subunits, but also repolymerizes to glutenin II during a subsequent resting stage. Ewart (1977) came to a similar conclusion in his consideration of mixing action, that glutenin macromolecules are broken during mixing. The points of scission are thought to be at the disulphide bonds, forming thiol radicals ($\text{—S—S—} \rightarrow 2\text{—S}^*$). The presence of free radicals in flour was shown by Redman et al. (1966) and Dronzek & Bushuk (1968). Sidhu et al. (1980a) showed that fumaric acid formed an adduct with cysteine residues of glutenin, a reaction that probably proceeds via addition of the thiol radical to the α,β double bond of fumaric acid.

The importance of stress-mediated scission of disulphide bonds in developing gluten is consonant with several lines of evidence. It is well known that increasing the absorption in a dough in the bakery increases the mixing time. Tipples and Kilborn (1977) found that the critical speed of mixing (the minimum mixing rpm necessary to achieve good loaf volume) increased as absorption increased. They could make a well-developed dough at 100 % absorption (using a high-quality Canadian wheat flour) by running the mixer at a high speed. As the dough consistency decreased, a higher rate of energy input was required to achieve the necessary stress to break disulphide bonds. The mixing time (at fixed rpm) required to develop doughs is highly correlated with the amount of glutenin in the flour (Orth & Bushuk, 1972; Singh, Donovan, & MacRitchie, 1990); more glutenin requires more energy input to be broken down and rearranged.

As disulphide bonds are broken, they reform between adjacent molecules that have been aligned along the lines of stress in the dough. Several different combinations can be envisioned:

$$2\text{—S}^* \rightarrow \text{—S—S—}$$
$$\text{—S}^* + \text{—SH} \rightarrow \text{—S—S—} + \text{H}^*$$
$$\text{—S}^* + \text{—S}_1\text{—S}_2\text{—} \rightarrow \text{—S—S}_1\text{—} + \text{—S}_2{}^*$$

The end result of these rearrangements is the linear glutenin polymers envisioned in Fig. 11.5.

A common picture of this process is simple thiol–disulphide interchange, as proposed by Goldstein (1957). This is unlikely, however, because such a reaction proceeds via nucleophilic attack of the thiolate anion on the disulphide. At dough pH (approximately five) less than 0.1 % of the thiol groups would be ionized (pK_a of —SH is approximately 8.5). These interchanges are more likely to involve a free radical mechanism, as described here.

While rearrangement of glutenin is the major consumer of mixing energy, it is not the only process occurring. The protein also incorporates lipids from the flour and any added emulsifiers and shortening. Grosskreutz (1961) used X-ray studies to conclude that developed gluten has a lamellar structure, with lipid bi-layers interleaved with protein layers. Other researchers (e.g. Chung, 1986) have proposed different models for the protein–lipid interaction. All that can be confidently stated is that most polar lipids and a significant fraction of non-polar lipids become tightly associated with the gluten protein (Chung, Pomeranz, & Finney, 1978; DeStefanis et al., 1977). The precise role played by these included lipids in dough properties (and final loaf volume) is still not fully clarified (Pomeranz, 1985).

The final result of development is thought to be an alignment of extended, nearly linear polypeptide chains, interacting through ionic and hydrophobic forces (Ewart, 1977). This will be discussed more fully below.

The Formation of Other Bonds

The dominance of the di-sulphide bond in dough formation is undisputed but other bonds are formed during mixing which contribute to dough development. The formation of hydrogen bonds has already been introduced. Disruption of the hydrogen bonds, e.g. with urea (Wrigley et al., 1998) weakens the dough while for metal chloride ions (e.g. sodium chloride) gluten strength is increased (Eliasson & Larsson, 1993) because higher charge densities result in more hydrogen bonding in the structure.

The recent application of spectroscopic techniques led Belton (1999) to develop the so called 'loop and train' model for the interaction of glutenin subunits in dough. In his model Belton postulates that individual glutenin subunits interact with one another by disulphide bonds at the ends of the subunits and hydrogen bonds along repeat regions. The 'loops' formed at repeat regions are where the water is bound and when extension is applied to the system, such as during mixing, the loops disappear and the 'trains' are formed. If the extension force is removed and the polymer relaxes then loops may be re-formed.

More recently a hypothesis has been developed (Tilley et al., 2001) for the formation of dityrosine cross-links in dough as a contribution to dough development. Tilley et al. postulated that the addition of a free tyrosine source prevents the overformation of tyrosine cross-links and enhances dough stability. Miller et al. (2005) examined the effect of adding free tyrosine and concluded that the effect of tyrosine addition varied with flour type and in one case a soft milling variety with weak gluten characteristics recorded an improvement in dough rheological properties as assessed with the DoCorder. The role of enzymic activity in the modification of tyrosine cross-links has also been reported (Tilley & Tilley, 2005).

Breakdown

If mixing continues after peak development is reached the dough becomes softer, less resistant to mixing action, and loses its ability to retain gases during proofing. SEM photographs indicate that the protein strands become shorter and thicker compared with those in optimally mixed dough (Amend & Belitz, 1990). The viscosity of dough proteins extracted into 1 % sodium dodecyl sulphate solutions were lower in over-mixed doughs compared to optimally mixed doughs, indicating a smaller average molecular weight (Danno & Hoseney, 1982).

Several α,β-unsaturated carbonyl compounds, such as fumaric acid, maleic acid, sorbic acid, ferulic acid and *N*-ethylmaleimide all increase the rate of dough breakdown during mixing (Schroeder & Hoseney, 1978). ^{14}C-Fumaric acid reacts with cysteinyl groups in gluten proteins during mixing; forming *S*-succinyl adducts (Sidhu, Nordin, & Hoseney, 1980a). It did not react with cysteine in soluble proteins or with added —SH compounds, leading the authors to conclude that it was combining with thiol radicals on the gluten proteins. Flour water solubles also contribute to the breakdown phenomenon (Schroeder & Hoseney, 1978; see above). Presumably it is the ferulic acid present in the WS pentosans which causes this effect. Fumaric acid and sorbic acid have been suggested as agents for reducing mixing time; at normal levels of use, and in practical situations, their effect may be too powerful, and the practice has not been widely accepted.

To summarize, dough breakdown appears to be simply a continuation of the process by which flour glutenin I is converted to (relatively) medium weight protein polymers that impart the desired rheological properties to dough.

Unmixing

Tipples and Kilborn (1975) reported an unusual phenomenon, the reversible decrease of resistance of a fully developed dough when it is mixed at a much lower rpm. When mixer speed is returned to that used for original development, dough consistency (and loaf volume potential) rapidly returns to that originally achieved. They termed this ‘unmixing’. It is not the same thing as allowing a dough to rest (no mixing action). If a nearly developed dough is allowed to rest, when the mixer is restarted the consistency first drops to the level that would be the case if it were mixed at low speed, then rises to full consistency. An explanation that has been made (Ewart, 1977) is that with low-speed mixing the gluten molecules are no longer being constrained to extended parallel alignment by shear forces. They tend towards more random configurations, and the low-shear mixing allows these molecules (presumably somewhat more globular in shape) to form interactions that stabilize the less extended configurations.

Air Incorporation

More than 60 years ago Baker and Mize (1941) showed that achieving a fine crumb grain depended, in part, on incorporating air into the dough and subdividing the air bubbles into small cells. These serve as nuclei for expansion of the gases formed during fermentation and baking. Junge et al. (1981) determined the course of air incorporation during mixing in a Mixograph (Fig. 11.10). Little air is incorporated during the hydration and blending stages of mixing. Entrapment begins only after the dough begins to develop resistance to mixing and some internal structure that

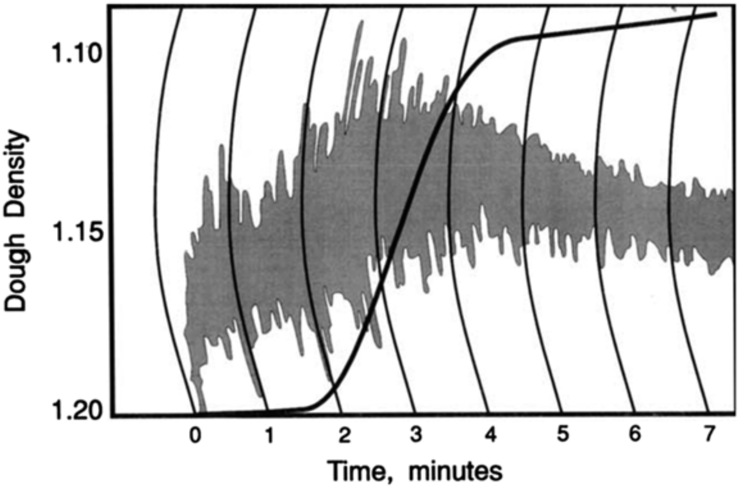


Fig. 11.10 Incorporation of air in dough mixed in a Mixograph (adapted from Junge, Hoseney, & Varriano-Marston, 1981)

Fig. 11.11 Structure of bread mixed using the CBP in 100 % oxygen atmosphere (courtesy *BakeTran*)

can envelop the air bubbles. An interesting point is that incorporation continues well past the mixing peak, into the breakdown portion of the mixogram. Thus it is not simply the elasticity of the dough that is responsible for entraining air; viscosity also seems to play a role (and perhaps also the ability of dough proteins to stabilize foams). Chamberlain and Collins (1979) found an interesting corollary to the observation of Baker and Mize; the entrapped gas must contain some nitrogen. They mixed doughs under a pure oxygen atmosphere. The final bread had an extremely coarse grain, with only a few large cells (Fig. 11.11). Their conclusion was that yeast consumed all the oxygen during early stages of fermentation, leaving relatively few gas bubble nuclei for expansion of fermentation gases during proofing and baking, resulting in large voids in the bread (see also Chaps. 2 and 4).

The Gluten Matrix

The final product of dough mixing is a visco-elastic mass that, after appropriate proofing and baking, produces an aerated solid called bread. Bread has a sponge-like structure (the voids are interconnected) with the structural elements being primarily gelatinized starch and denatured protein. The rheological characteristics of dough are primarily responsible for achieving the desired result. Dough rheology, however, is (or should be) traceable to the nature of the matrix elements which are, in this case, gluten-forming proteins. A great deal of dough research has to do with measuring its rheological characteristics, correlating them with bread characteristics (the effects of additives such as oxidants, reductants and surfactants, proofing behaviour, loaf volume and crumb grain), and attempting to connect those measurements with such physical characteristics of gluten as can be determined. Much of this research has been presented and reviewed. Some excellent sources are Bloksma and Bushuk (1988); Bloksma (1990a, b) for Cauvain (2012a) and Eliasson and Larsson (1993); Faridi and Faubion (1990) and Hoseney and Rogers (1990).

While much more is known about dough now than, say, 70 years ago, the current situation might be summarized as follows:

- Dough is an extremely complicated system that cannot be fully described in simple rheological terms (springs and dashpots);
- Many practical instruments make measurements that are difficult to interpret in fundamental rheological terms, and may or may not be applicable to events during proofing and baking;
- Statements about the structure of gluten protein polymers are still largely hypothetical;
- There is great scope for further fundamental research in this area.

Dough Rheology

Numerous discussions of dough rheology are available. Menjivar (1993) presents basic rheological concepts, while Bloksma and Bushuk (1988) apply them more specifically to dough. An important point is that two types of stress are involved: shear and extensional (Fig. 11.12). In shear stress opposing forces are applied parallel to each other, in opposite directions to the matrix element. A strain is set up at right angles to the two surfaces. If it remains constant (and the element returns to its original shape when stress is relieved) the deformation is elastic, and elastic modulus is defined as: $E = \text{stress/strain}$. Intuitively, E is larger for more ‘solid’ materials;

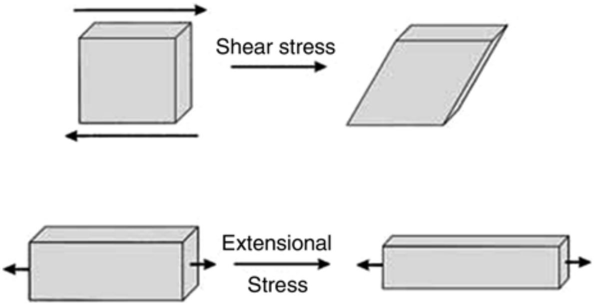


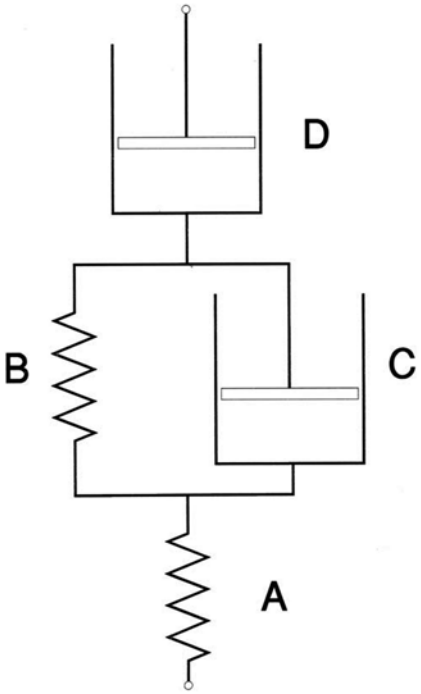
Fig. 11.12 Diagram of shear and extensional deformation

a cube of hard rubber has much higher value of *E* than a cube of sponge rubber. If the strain decreases as a function of time, then when stress is relieved the element does not return to its original shape, and the deformation is viscous. For a simple (Newtonian) fluid viscosity is defined as $\mu = \text{stress/strain rate}$. In a dough mixer, Mixograph or Farinograph shear stress is the dominant mode. In extensional stress the opposing forces are applied in opposite directions, but at the opposite faces of the matrix element (Fig. 11.12). The definitions of elastic modulus and viscosity are the same as in shear stress, but the dimensional effects on the element are different. Whereas in shear the element maintains the same cross-section, in extension the cross-section decreases as the element lengthens (the volume remains the same in both cases). Extensional stress is applied to a dough by the Extensograph or Alveograph, and also during fermentation (proofing) and baking (oven spring).

Dough is visco-elastic, that is, it has both viscous and elastic characteristics. The simplest mechanical model that can be used to interpret rheological studies on dough is the Burgers body (Fig. 11.13). When stress is applied to dough the immediate response is elastic deformation (element A), followed by a delayed elastic response due to stretching of element B as element C undergoes viscous flow. Viscous flow by element D relaxes the instantaneous elastic strain on A. When the stress is relieved, any remaining elastic deformation of A is immediately removed. The removal of strain on element B is relieved only as C undergoes viscous flow (in the opposite direction). There is no force to reverse the flow that has occurred in D, so that amount of dough deformation remains when final equilibrium is reached.

A typical creep and recovery curve is shown in Fig. 11.14. The strain (deformation) continues as long as stress is maintained on the dough piece. The contributions of the various elements of the Burgers body can be identified on the curves, based on the previous discussion. However, it should be noted that each element is a composite of many elastic and viscous elements in the dough, so that element A (for example; Fig. 11.14) actually represents a spectrum of elastic moduli and D comprises a range of viscosities. By collating the results of many such creep and recovery studies an equation relating apparent dough viscosity (element D) to shear stress (Bloksma & Bushuk, 1988, Figs 6 and 7) was developed. Dough is a shear-thinning material, and its viscosity was calculated as 1.6×10^5 Pa s at a shear rate of 10^{-3}/s and 1.1×10^2 Pa s at a shear rate of 10^2/s.

Fig. 11.13 The Burgers body mechanical model of dough rheology



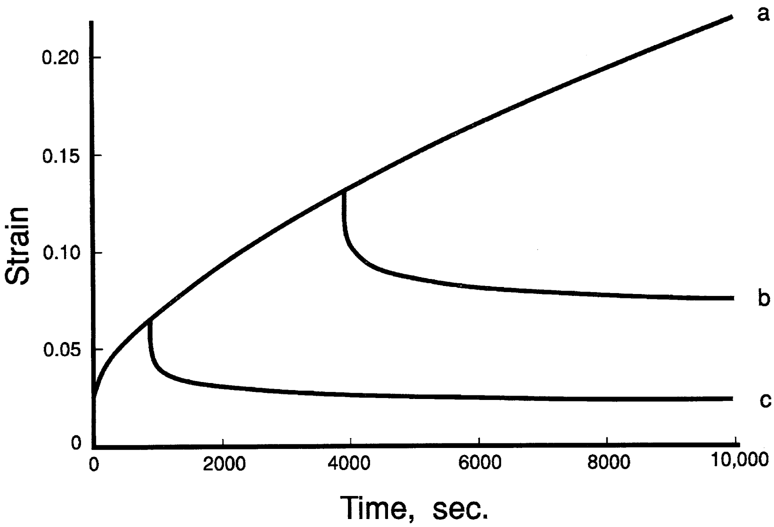


Fig. 11.14 A typical creep and recovery curve for dough under extensional stress. (**a**) Stress maintained throughout, (**b**) stress removed after 4,000 s, (**c**) stress removed after 1,000 s (adapted from Hibbered & Parker, 1979

Bloksma (1990a) presents some figures relating shear rates in various laboratory instruments to the situation in dough. They are:

- Dough mixers, 10–100/s;
- Farinograph, Mixograph, 10/s;
- Extensograph, Alveograph, 0.1–1/s;
- Proofing, 10^{-4} to 10^{-3}/s;
- Baking (oven spring), 10^{-3}/s;

The problem with relating test results to actual dough function thus becomes apparent. Extensograph and Alveograph testing involves dough with a viscosity of $(2–8)\times10^3$ Pa s (calculated according to Eq. 1 of Bloksma & Bushuk, 1988), some two orders of magnitude lower than viscosity in proofing dough. While results from such testing may correlate with dough properties (and qualities such as loaf volume), these should not be taken as 'explanations' of what is actually occurring in the dough.

A typical extensogram is shown in Fig. 11.15. The parameters of interest are *R* (the height of the curve at 5 cm extension), *E* (the length of curve until the dough piece breaks) and *A* (the area under the curve). A dough having large values of *R* but small *E* is extremely 'bucky', while one with small values of *R* and large *E* is very soft and pliable. Extensogram curves have been transformed into stress–strain diagrams (Rasper, 1975) but little use has been made of this work. More often, one or more of these measurements is correlated with dough properties. One example is the report by Singh et al. (1990), where they found that *E*, *R* and *A* for a series of 15 flours were all highly correlated with final loaf volume (the three parameters were strongly inter-correlated, as might be expected, so there was really only one Extensograph test of loaf volume potential).

Bloksma (1990b) expresses the opinion that:

> The only rheological properties required for good breadmaking performance appear to be extensibility and a sufficiently large viscosity. Extensibility can be translated into structure; a large quantity of high-molecular-mass glutenins enhances extensibility. The latter of these two conditions, a large viscosity, is met by virtually all doughs; it has no discriminating power.

Before considering the meaning of the term extensibility, we must think about the structure to which Bloksma refers.

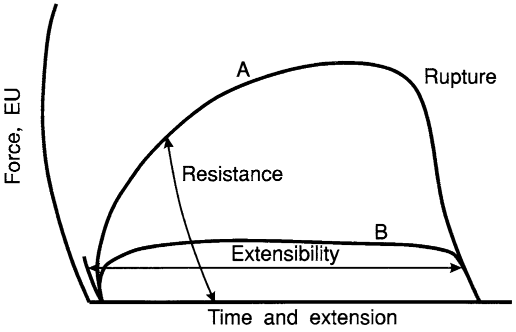


Fig. 11.15 An extensogram. (**a**), Dough having good elasticity and good breadmaking properties; (**b**), dough with poor elasticity and poor breadmaking properties

Gluten Structure

Meredith (1964) proposed that in developed dough the gluten consists virtually of one giant molecule, comprising glutenin extensively cross-linked by disulphide and other bonds. The comparison was made (by other authors) to vulcanized rubber. Bloksma (1990a and references therein) pointed out that this comparison was invalid; temperature changes had opposite effects on the elastic and viscous moduli for dough and for rubber. Ewart (1968, 1977) pointed out that there were several other lines of evidence that substantiated rejection of the 'giant molecule' hypothesis, and proposed that gluten structure was due to interactions between long, linear glutenin polymers. He made the analogy between dough 'strength' and the strength of a rope; while rope fibres are not physically cross-linked; the longitudinal forces between fibres give it a high elastic modulus (resistance to deformation in extensional shear). The glutenin 'fibres' impart elasticity to dough by virtue of the (non-covalent) bonds between them. The linear glutenin hypothesis of Ewart envisions numerous long glutenin molecules, aligned somewhat as shown in Fig. 11.16a. The contribution of gliadin to dough properties cannot be ignored (van Lonkhuijsen et al., 1992; Weegels et al., 1990). The scheme in Fig. 11.16b includes gliadin molecules, which contribute to the interactions between glutenin chains. Some of the possible consequences for dough rheology due to these models are discussed below.

Bonding Between Protein Chains

There are three possible types of non-covalent bonds in dough: ionic, hydrogen and hydrophobic bonds (Wehrli & Pomeranz, 1969). Glutenin has a low density of ionizable (acidic and basic) amino acids, so that such bonds would appear to be relatively unimportant in dough. At low pH (for example, in a sponge subjected to long

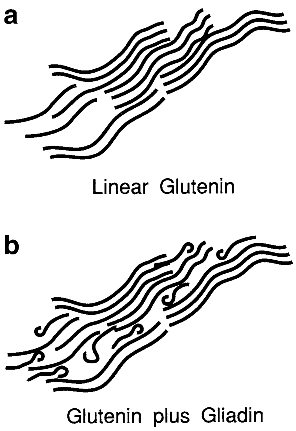


Fig. 11.16 Models of the structure of gluten. (**a**) The linear glutenin hypothesis (Ewart, 1977), (**b**) inclusion of gliadin in the structure

fermentation with consequent formation of much acetic and lactic acid) protonation of the few carboxylic side chains present leads to a significant net positive charge on gluten proteins, weakening inter-chain interactions by ionic repulsion.

The high percentage of amide (glutamine) side chains contributes to extensive hydrogen bonding between chains. The importance of this interaction to gluten elasticity was clearly demonstrated by Beckwith et al. (1963). They treated gluten with methanolic hydrochloric acid, converting amide groups to esters. Conversion increased solubility, decreased intrinsic viscosity of protein solutions and decreased cohesion of the hydrated gluten. Individual hydrogen bonds are relatively weak (about 4.2–6.3 J/mol or 1–1.5 kcal/mol) but the presence of large numbers of them lends overall strength to the inter-chain interactions. The fact that the resistance of dough to elastic deformation decreases with increasing temperature (Bloksma & Nieman, 1975) emphasizes the importance of hydrogen bonds in the proteins. Besides inter-chain bonding, hydrogen bonds also stabilize the β-turn spirals in the central portions of glutenin molecules. These play a role in the interpretation of elasticity presented below.

The relative importance of hydrophobic bonding in dough is difficult to assess accurately. When a dough is mixed in deuterium oxide (D_2O) rather than ordinary water (H_2O) it is much more elastic (Hoseney, 1976). Both hydrogen (deuterium) bonds and hydrophobic bonds are stronger in the presence of D_2O, so this test is not decisive. The addition of various salts, however, does discriminate between the two types of bonds. The Hofmeister (lyotropic) series arranges ions according to their ability to 'salt in' (increase hydration of) proteins as well as other hydrophobic materials. This is interpreted as being primarily an effect on water structure. Lyotropic salts (e.g. magnesium thiocyanate) decrease water structure and increase solubility of ('salt in') hydrophobic chains. Non-lyotropic salts (e.g. sodium chloride and sodium phosphate) enhance water structure and decrease solubility of ('salt out') hydrophobic chains (Tanford, 1973). (The term 'chaotropic' is used synonymously with lyotropic. The advantage is its mnemonic nature; a chaotrope is an ion or molecule that increases the 'chaos' in water structure.) The effect of salts on dough elasticity, absorption and mixing tolerance has been studied by numerous authors (Holmes & Hoseney, 1987; Kinsella & Hale, 1984; Salovaara, 1982). Lyotropic salts (e.g. sodium thiocyanate) increased water absorption by the protein (enhanced its solubility in water), while non-lyotropic salts (e.g. sodium fluoride) decreased absorption. The reported results have been interpreted in terms of protein hydration (Stauffer, 1990), but they can equally well point to the role of hydrophobic bonds in gluten structure.

Glutenin and gliadin are rather hydrophobic proteins, as shown by numerous studies using gel chromatography on hydrophobic media such as phenylsepharose (Chung & Pomeranz, 1979; Weegels et al., 1990). Chung and Pomeranz (1979) found that acid-soluble glutenin extracted from a good-quality flour was more hydrophobic than that from a poor-quality flour. Hydrophobic gliadins increase bread loaf volume, while hydrophilic gliadins decrease loaf volume (van Lonkhuijsen et al., 1992; Weegels et al., 1990). Flour lipids (Daniels et al., 1976; Wootton, 1976) and added emulsifiers (DeStefanis et al., 1977) are bound to gluten during dough mixing, which must be in large part due to hydrophobic interactions. Hydrophobic interactions are weaker than hydrogen bonds (approximately 2,500 J or 600 cal per CH_2 group) but again, because of the rather large number of available interaction sites, the overall contribution to gluten structure is significant.

The relative contributions of ionic, hydrogen and hydrophobic bonds to aggregation of glutenin proteins were estimated to be 17.3, 56.3 and 26.4 %, respectively, in a good-quality gluten, and 12.8, 80.1 and 7.1 %, respectively, in a poor-quality gluten. In discussing chain interactions in gluten, then, hydrogen bonding (glutamine side chains) is of primary importance, and hydrophobic interactions play a lesser, but not negligible, role, particularly when lipids are involved.

Gluten Elasticity

What is the source of gluten elasticity? A reasonable hypothesis (Tatham, Miflin, & Shewry, 1985) is that β-turn spirals, and the hydrogen bonding between them (which connects them into β sheet structures), can be slightly extended and act as springs (Fig. 11.17a). Under stress, hydrogen bonds can be slightly extended. While each such extension might amount to only a fraction of a nanometre, summed over many thousands (or even millions) of such deformations, the total dough deformation can amount to several percent, as indicated in Fig. 11.13. While Tatham et al. (1985) proposed an analogy with elastin, Bloksma (1990b) pointed out that elasticity in the two proteins has opposite temperature dependence.

A second source of elasticity could be entropic. Ewart (1977) considered the individual glutenin molecules to be roughly spherical in shape; several such spheres are concatenated to form the ‘linear glutenin’ of his hypothesis. Under stress each glutenin molecule could be extended (Fig. 11.17b) into a less-favourable configuration. Relieving stress allows the protein molecule to recoil to its preferred (lower-energy) state. A similar picture has been suggested by Amend (1995), based upon SEM pictures of extended (stretched) gluten membranes.

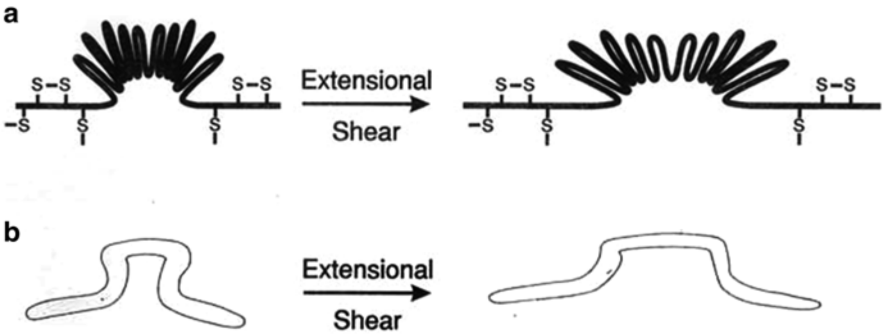


Fig. 11.17 A proposal for the source of glutenin elasticity. (**a**) Extension of the β-turn spirals and sheets, (**b**) deformation of compact glutenin molecules into a more linear configuration

Gluten Viscosity

For dough to undergo viscous flow the glutenin molecules must move relative to each other. Several mechanisms have been proposed by which this might occur. At the time Goldstein (1957) suggested sulfhydryl–disulphide interchange as such a mechanism, disulphide cross-links were considered to be the most important feature of gluten structure. Today that picture of the 'giant molecule' seems unlikely, for reasons given above. In freshly mixed dough, however, thiol free radicals appear to be present. These disappear during a 10 min resting period (Graveland et al., 1985), probably through interaction with disulphide bonds. Thus during this relaxation period (bulk fermentation or floor-time in common parlance) the dough undergoes viscous flow (releasing elastic stress) via thiol–disulphide interchange.

Movement of glutenin molecules is more likely to occur via hydrogen bond and hydrophobic bond interchange. Some of this may happen as a result of molecular motion and Brownian movement. A certain fraction of the hydrogen bonds between chains can be disrupted, and one chain move relative to another, before re-establishing hydrogen bonds. This happens more readily at higher temperatures, and dough viscosity decreases by a factor of five over the range 26–60 °C (79–140 °F) (Bloksma, 1990a).

Gliadin may also play a role as a mobile, small-molecule intermediary of these interchanges. While gliadin can certainly interact via hydrogen bonding because it contains a higher percentage of glutamine than glutenin, the fact that its hydrophobicity contributes to bread quality indicates involvement of this aspect of its nature, as emphasised in Figure 11.18. By facilitating the movement of adjacent glutenin molecules, gliadin may be characterized as 'molecular ball bearings'.

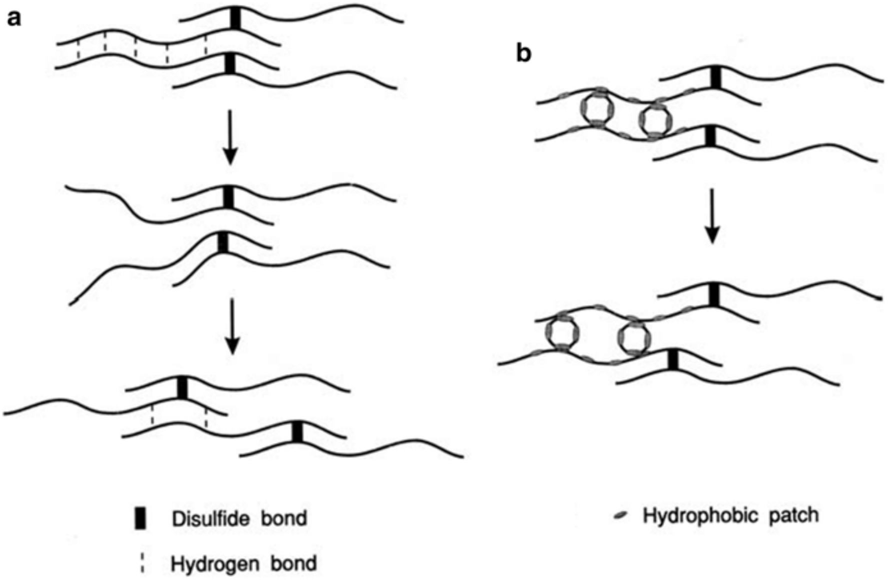


Fig. 11.18 Viscous flow and dough relaxation. (**a**) Brownian motion and chain realignments; (**b**) involvement of gliadin in glutenin realignment

A portion of gluten viscosity may be simply due to a high concentration of macromolecules in the aqueous phase. The viscosity of gum solutions increases tenfold for each 1 % increase in concentration. The concentration of glutenin can be estimated at 15 % as a lower boundary. Solutions of non-gelling gums at this concentration show a viscosity of the order of 10^6 Pa s or more. Viscosity is also strongly dependent on the average molecular weight of the protein, and glutenin molecular weights are of the order of 10^6 Da. Even if there were no interactions between glutenin chains, one would intuitively predict a high viscosity for a suspension such as that found in dough.

The postulated formation of links between gluten proteins and WS pentosans (Hoseney & Faubion, 1981; Fig. 11.2) must not be overlooked. To the extent that this happens in dough, the glycoprotein (pentosan–glutenin) would have an even higher molecular weight than the glutenin complex alone, thus increasing viscosity. It would also hinder relaxation, increasing dough elasticity.

Extensibility

Extensibility is difficult to define in precise rheological terms, although it is easy to find familiar instances; bubble gum and bread dough are common examples. Under extensional stress, the material thins to form a membrane. At the limit of extensibility, holes appear in the membrane and expand as extension continues. In the Extensograph this corresponds to the distance the centre of the dough piece (of defined initial dimensions) can be stretched before the dough ruptures. To some degree this distance depends on the rate of extension; at a lower rate the dough will extend further before rupturing. Thus, viscous flow is involved to some degree. Elasticity is involved in defining the amount of stress that can be applied before the dough piece breaks (tensile strength). With a less elastic dough the amount of extension may be the same as for a more elastic one, but the actual stress at rupture will be higher for the more elastic dough (Fig. 11.15).

Slade et al. (1989) show polarized light photomicrographs of stretched films of a synthetic chewing gum base (polyisobutylene elastomer) and of gluten. The similarities between the two photographs are striking. These films were stretched in one direction, and the authors point out that film strength is maximum along that axis, and minimum at right angles. Holes begin to form when the fibrils separate laterally, and the holes expand perpendicularly to the direction of stretching. In bread dough during proofing and expansion of gas cells, and in the Alveograph, extension of dough is biaxial with the gluten film being stretched along both dimensions. (In the third dimension, perpendicular to the film surface, the membrane grows thinner.) This results in the maximum strength for gluten membranes.

Bloksma (1990a) reviews at some length the various components of extensibility (viscosity, elasticity and tensile strength) that influence the overall performance of dough during proofing and baking. His discussion emphasizes that all those factors of importance to the baker are developed during dough mixing. In other words, he confirms the experience of every bakery technical service person: if a bakery is having trouble producing good bread, one of the first places to look is at the mixer. If the mixing is right, the rest of the process should be relatively trouble-free.

Stickiness and the Behaviour of Dough During Processing

One dough property which has major implications for dough processing but is still not understood is stickiness. In the commercial bakery, especially where mechanical handling of dough is practised, stickiness is of major importance as equipment surfaces may become smeared with dough. This is especially true with rounder and final moulders (Chap. 4) and the progressive build-up of traces of dough on metal surfaces can be significant enough to bring processing halt. Plant stoppages clearly need to be avoided because they increase waste, disrupt production and reduce production capacity. A particular problem in commercial is that the practical reaction to ‘sticky’ doughs is to reduce the recipe water level. To some extent this water reduction does have an ameliorative effect but the relationship between dough softness (consistency) is not an absolute one. Indeed lowering recipe water levels too far can result in other quality defects arising from the interaction of the stiffer dough with moulding equipment (Cauvain & Young, 2008). The alternative to reducing recipe water levels to combat dough stickiness is to use a liberal dusting of the dough with flour.

Observations carried out on dough processing readily reveal that dough stickiness is associated with the manner in which the dough is processed. In particular it can be readily seen that subjecting the dough to shear (Menjivar, 1993) increases the property of dough which bakers interpret as stickiness. In commercial practice shearing of dough is most commonly seen during the dividing and moulding processes. A further practical observation is that stickiness is to some extent, transitory in that the rheological properties of dough which rests after being sheared change and there is a noticeable decrease in dough stickiness. Even the gentle manipulation of a sticky dough by hand results in the loss of dough stickiness.

The reasons behind dough stickiness are not well understood, in part because of the problems of measuring this particular dough property. A number of methods are available for measuring dough stickiness (Cauvain & Young, 2009) but often manipulation and passage of time associated with testing the dough reduces the ability of a test to measure the property concerned. Recently a test has been developed which attempts to mimic high shear dough processing (Cauvain, 2012b). In the test a knife blade is driven downwards into a dough piece held in a box of fixed dimensions. A slot in the lid facilitates the movement of the blade down through the dough piece (Fig. 2.1a) and upon withdrawal (Fig. 2.1b) the stickiness of the dough is measured using the negative curve so obtained (Fig. 2.2). In its action the test is similar to that of a dough divider and as the cut surface of the dough is not exposed to the air or manipulation (other than the cutting blade) some of the transitory nature of stickiness is avoided.

Table 11.2 Effect of salt on dough stickiness (as measured with the Warburtons dough stickiness test)

Salt level (% flour weight)	Stickiness (kg) (adhesion peak)	Work of adhesion (kg.s) (area)
2 (standard)	0.82	0.94
1 (50 % reduction)	2.75	3.71

Higher values indicate stickier dough

The open question is then what fundamental changes causes dough to become sticky? Perhaps one clue is provided by the observations that when salt levels in dough are reduced, stickiness increases (Table 11.2). Sodium chloride is of course, very good at binding water (Cauvain & Young, 2008), probably more so than wheat protein and pentosans. It would be possible to consider that some of the water bound into the dough protein structure may be temporarily released when the dough is exposed to significant shear forces during processing. The temporarily free water may well be a significant contributor to dough smearing and stickiness. Upon resting or under gentle manipulation (by hand or sheeting) it appears that the attractive forces in the dough are able regain control of the temporarily free water. If this is the case then it is likely that hydrogen bonding is involved. Another observation worthy of investigation is the addition of sugars such as sucrose which cause the dough to become both softer and stickier.

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Chapter 12
Wheat Milling and Flour Testing

Introduction

Flour milling is a technology which combines food science and engineering with the art of the practical miller. This chapter aims to help define the science and the art of a process which produces one of the most versatile of bakery raw materials and aims to provide a background to the link between wheat, the milling process and the properties of the final flour.

Wheat has been a major food source for thousands of years. The unique properties of its proteins when hydrated have given it a flexibility which has made it ideal for a multitude of different bread products from the flat breads of the Mediterranean and equatorial countries, e.g. chapatti, pizza and ciabatta, through to the sandwich and free-standing breads commonly seen in Europe, America, Australia, New Zealand and South Africa. We must remember that the wheat grain is a seed that is designed to protect the embryonic plant from the rigours of the outside world until conditions are right for its germination and subsequent growth. A representation of the structure of the wheat grain is given in Fig. 12.1. The outer bran coat with its unique physical structure which folds the seed in on itself to form the characteristic crease, protects the seed. As a result of this complex shape, milling engineers have developed a series of mechanical operations which aim to break through these protective layers to extract the endosperm with its maximum food value.

Flour milling can trace it origins back to prehistory, but the modern systems known as gradual reduction flour mills have only been developed over the last 200–300 years. Early humanity used pestles and mortars to grind wheat, pounding it to make a crude wholemeal flour. This basic milling technique developed into saddle rubbing stones and eventually to rotary grinding stones (querns), with evidence for use of the latter dating back 7500 years. While initially querns would have been hand operated, the enlargement of communities led to the development of larger stones with increased capacity using animals and later water power. Wind power has been used since the twelfth century and steam was introduced in the eighteenth

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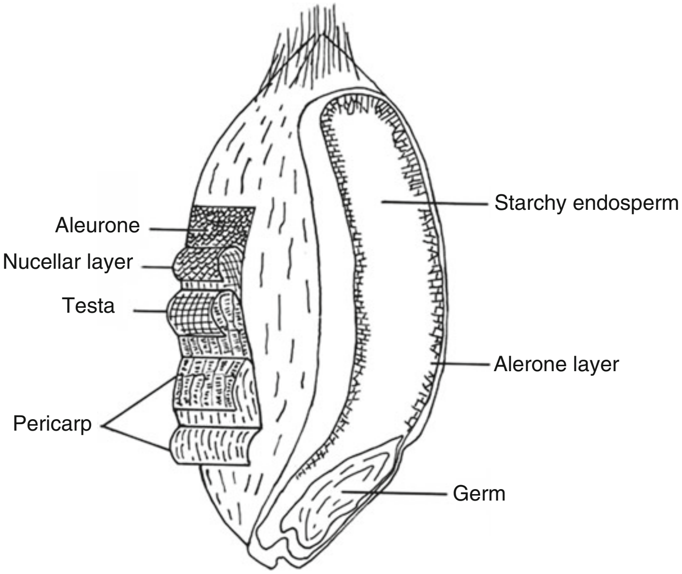


Fig. 12.1 The wheat grain (not to scale)

century, but whatever the power source the basic principle of grinding wheat grains between two stones to produce a flour remained essentially unaltered. Indeed, even in today's highly technological society, wheat ground to flour between two stones is perceived by some to be a superior product.

The basic one-pass system between two stones does have its drawbacks in that the bran skins and germ are ground as finely as the endosperm and the separation of these parts from one another by sifting can be difficult. To overcome this drawback a system was developed by French and Hungarian millers in the seventeenth and eighteenth centuries which linked together several sets of stone mills, the gap between each successive pairs of stones being set slightly closer than the one before. After each pass the resultant meal was sieved and some bran separated before the remaining material was sent to the next set of stones. As a result flour colour improved and a 'white' flour was produced which contained higher proportions of the grain endosperm with improved breadmaking potential. The development of the gradual reduction flour milling process had begun.

The Modern Flour-Milling Process

The principles of modern milling are still very much the same as described for stone grinding above, except that now the wheat is ground between pairs of cast-iron or steel rolls before the stocks (the intermediate particles) are sieved and then reground. At each grinding stage a little white flour will be produced and up to four or five other sieve separations are made. Because the particle sizes of the various sieve fractions will differ, they will all be treated separately on different rolls with different settings. At first sight the system in a modern flour mill appears to be quite complicated, but over the next few pages some attempt will be made to shed some light on the whole process to make it easier for the student to follow.

Delivery of the Wheat

Flour mills have been and still tend to be built near their major source of wheat supply. At the beginning of the twentieth century in many countries they were often built at ports to take advantage of imported grain. Those built inland were built adjacent to canals, rivers and railways to minimize the cost of transport. Large 20,000 tonne bulk grain carriers are still used to transport wheat around the world by sea, and small 1500 tonne coasters are used in more local waters. A discussion of the full extent to which grain is transported by sea can be found elsewhere (Sewell 2003).

Raw material and transport costs continue to be an important factor in all industries, many countries prefer to use as much of their home-grown wheat varieties as possible. This desire prompted a response by wheat breeders throughout the world has led to the development of wheat varieties with improved breadmaking performance, and imports can be reduced to some extent. In consequence the dependence on port-based mills has declined in some parts of the world. Mills can now be built closer to the wheat growing areas and the raw material transported by road. However, the demand for wheat remains high in many countries who do not have the land or climate to grow large quantities of wheat and so the import and export of which continues to rely heavily on sea transport and flour mills sited in coastal regions.

When wheat arrives on the mill site it will need to be sampled so that tests can be carried out to determine quality against the agreed purchasing specification. Sampling has to be done efficiently so that the results obtained from the tests are representative of the whole load (Cauvain 2009; Wrigley and Batey 2012).

Generally sampling is done in one of two ways

- With a manual spear which requires the operative to climb on top of the load and force the spear into the load of grain. Turning the handles takes a range of samples at various points along the length of the spear. While this system is simple and cheap it is prone to abuse. Pushing the spear vertically into a load is very difficult, and the temptation will always be to push it in at a shallower angle, with the result that wheat in the bottom of the lorry will not be sampled. Walking on the load to sample it is an unacceptable practice for a foodstuff and as a result many more mills are changing to the pneumatic sampler.
- More reliable is the use of a pneumatic sampler. It can either be steered manually, or pre-programmed to follow a defined sampling pattern, and is driven vertically down into the wheat to take samples at all depths. The intake operative no longer has to walk on the wheat, so that the risk of contamination is reduced although the lack of personal contact does have a slight disadvantage in

that it puts a greater emphasis on the laboratory staff to identify problems, such as contamination and taints, which previously could have been more readily spotted in the lorry, truck or railcar.

Wheat Testing

On arrival in the mill laboratory the wheat sample is thoroughly blended to ensure that the results will be representative of the whole delivery. It is important that tests are carried out on the wheat prior to tipping the lorry for the following reasons:

- To ensure the wheat is of the quality required;
- To make sure it is not contaminated with foreign bodies or infested with insects;
- To ensure it will be stored with wheats of similar quality.

The tests carried out will vary according to the type of mill, and the flour being produced (Cauvain 2009), but will at least include some of the following:

Appearance, off-odours and taints. Initially the wheat is inspected by trained laboratory staff who will examine it for any unusual odours, mustiness from damp, mouldy wheat, or evidence of contamination from the transporting vehicle, either from a previous load, or even from the fuel used.

Screenings (impurities). Screenings is a general term applied to all impurities in a parcel of wheat. They can be divided into two main types, intrinsic and extrinsic.

Intrinsic impurities are those which are reasonably associated with the wheat itself, but for obvious reasons are not required in the finished flour, e.g. shrivelled or diseased grain, straw, weed seeds or seeds from other crops growing in the vicinity of the wheat (cockle, millet bindweed, etc.) and ergot (Williams et al. 2009). The latter is a fungus associated with wheat but more commonly with rye. It appears as dark purple structures which replace the individual ears of grain and can contain ergotoxin, a poison that may lead to abortion in both humans and livestock. Extrinsic impurities are contaminants of wheat which should not reasonably be present, e.g. string, paper, nails, wire, wood, or evidence of contamination from rats and mice. Such materials can come from contamination in storage, or could have been picked up during harvesting (combining).

A simple sieving test based on using two slotted screens with holes of different sizes is used to check for impurities at intake. A sample of wheat is placed on the top deck and the apparatus is shaken either mechanically or manually. All impurities larger than wheat are retained on the top deck (3.5 mm), the wheat grains themselves are retained on the middle deck and any fine impurities pass through to the bottom container. These fine impurities can be further inspected for signs of infestation before being weighed together with the coarse impurities to give a total figure which is expressed as a percentage of the original wheat sample. If this figure exceeds the specification agreed with the wheat merchant, then the wheat can be rejected. High levels of screenings will contribute to poor extraction rates on the mill, black specks in the flour (especially wholemeal) and possibly taints. In relatively small amounts they will not be a problem and should all be removed when the wheat is cleaned in the part of the mill known as the screenroom.

Wheat density. This property is commonly referred to as hectolitre weight or bushel weight. Various manufacturers produce equipment for its measurement and the most common apparatus all work in a similar manner (Cauvain and Young 2009a). A cylinder of known volume is filled using a standard method and weighed. The figure obtained is converted to kilograms per hectolitre (kg/hl) and is one of the first tests carried out to determine the ‘quality’ of the grain. Hard breadmaking wheats will have a higher figure, in excess of 80 kg/hl, compared with softer biscuit types at around 70 kg/hl. A poor harvest will give low hectolitre weights because of the presence of small shrivelled and sprouted grains. The milling industry around the world has to maintain the optimum amount of flour from the wheat, which is referred to as the ‘extraction rate’. Low hectolitre weights will give a poor extraction rate, can cause too many wheat grains to be removed in the screenroom, will produce a dirty ‘specky’ flour and are commonly associated with low Hagberg Falling Number in the wheat and subsequent flour.

Having assessed the whole grain a sample of the wheat can be ground to a flour in a laboratory mill and further tests carried out. The choice of tests to be carried out varies according to the particular needs of the miller and location. There is no common consensus view as to which tests are the most important though commonly they will include the measurement of protein content and associated gluten-forming properties.

Protein content. Generally, the value for wheat protein content is accepted as the determination of nitrogen × 5.7. The classic method for assessing protein content uses the Kjeldahl apparatus though this has now been largely superseded by the Dumas method (ICC Method 167). Both methods take far too long for use at the point of wheat intake. More rapid methods for protein determination have been developed, the most common one being based on near-infrared (NIR) (Cauvain and Young 2009a) which can produce a result in approximately 25 s. Regular updating of the NIR calibration is required to ensure the reliability of the results obtained with this technique.

Protein content and quality are of vital importance in flour milling. They are the characters which make wheat unique and are the main properties on which wheat is traded, with higher protein wheats generally commanding a higher value. Protein contents can vary widely from one delivery to another and so accurate measurements are required to be able to segregate the wheat into suitable protein bands which can then be blended to give consistent grist formulations for subsequent milling. The effects on protein of product character are discussed below.

Gluten content. For this test a sample of flour is prepared from the ground wheat by sieving. The gluten quality is tested using a small mixing machine which kneads the flour and salt water into a dough for a set time, before washing the starch away (ICC Method No. 106). A salt solution is used to help keep the gluten cohesive.

The remaining wet gluten sample can then be weighed and manually assessed for its vitality and strength. A more basic approach is to prepare a small dough manually in a beaker and the starch washed away under a running tap. Generally a smooth gluten with a good light grey colour indicates a good breadmaking wheat. Wheat which has been dried incorrectly may have damaged protein so that its gluten will have a very short and 'bitty' character and in extreme cases the sample may not even form a gluten. In some hot climates it is possible for the gluten-forming properties of the wheat proteins to be affected by conditions in the field.

Moisture. There are several ways to determine moisture content in the wheat laboratory. NIR is now often used and also heat balances. In the latter case, an infrared or incandescent heat source is mounted over an electronic balance and the sample is heated until a constant weight is achieved. Conductive methods are also available but the key factors are that they have to be quick and accurate. Oven drying methods, such as 4 h for 130 °C for 1.5 h (BSI 1987) take far too much time for them to be used at wheat intake but are they are the standard methods against which the rapid methods are calibrated.

The moisture content of wheat is important to both farmer and miller because wheat can to be stored for up to 12 months before use and therefore the moisture content has to be low enough to avoid spoilage during storage. As a general rule the moisture content should not exceed 15 %, but if the miller intends using the wheat reasonably quickly then slightly higher figures might be accepted. In cooler, wetter environments the harvested wheat may be dried before storage to ensure that the moisture content is low enough for storage.

Hagberg Falling Number. This is a measure of the cereal *alpha*-amylase in wheat, and is a critical parameter for flour used in many bakeries (Chap. 3). To carry out the measurement a suspension of flour from the laboratory grinder and water is blended in a test tube then heated in a boiling water bath and stirred continually for 60 s. At the end of this period the stirrer is brought to the top of the tube and released. The *alpha*-amylase in the sample slowly breaks the solution down converting the starch to dextrins and the stirrer gradually sinks under its own weight at a rate which depends on the viscosity of the solution in the tube. When the stirrer reaches the bottom of the tube the test is stopped. The resulting time in seconds is the Hagberg Falling Number (HFN), and is proportional to the amount of cereal *alpha*-amylase present, the higher the figure the lower the amylase (ICC Method No. 107). The HFN includes the first 60 s mixing, so 60 is the lowest figure possible. Figures over 350 s tend to be unreliable because the contents of the test tube will be at the same temperature as the water bath and the amylase will have been denatured. This would normally happen at temperatures above 75 °C (167 °F).

Hardness. This is a measure of the wheat endosperm texture and indicates to the miller the manner in which the endosperm is likely to fracture during the milling process. As a general rule hard wheats are used in breadmaking and softer wheats are used for biscuits and cakes. However, this is a simplistic classification and cannot be considered as absolute, there are many hard wheats that do not make good quality bread and would only be considered as 'feed' wheat, and there are also some so-called breadmaking wheat varieties that can be classified as soft milling.

Wheat hardness testing can be carried out using a specially calibrated laboratory mill (Hook 1982), where the time taken to grind a standard volume of material is measured. NIR may be used (AACC Method 39–70A, 1995) and has the advantage of reducing the number of tests carried out by the laboratory technician and therefore speeding up the whole of the sample testing process. The Perten single-grain kernel characterization system has been developed to deliver an automated and objective measure of wheat hardness (Gaines et al. 1996). The force-deformation characteristics of wheat grains are determined by crushing a number of individual grains, commonly around 300. The same equipment also provides information on grain weight, diameter and moisture.

Wheat varietal identification. Some millers will buy blends of wheat while other may buy specific varieties. Both approaches to wheat purchasing have their advantages and disadvantages. In the case of wheat purchase by variety some check may be carried out by the miller at intake to ensure that the delivery is of the specified variety. The morphology of wheat grains varies from variety to variety and visual inspection by trained and experienced mill operatives can often identify the varieties being received.

An alternative to visual inspection is to carry out an electrophoresis test (BSI 4317: Part 30 1994). In essence the test splits the protein fraction into individual amino acids and records them as a unique pattern which can then be used to compare an unknown pattern with those from known samples. Electrophoresis is not a common test at wheat intake; however, it is very valuable for ensuring authenticity when specific varieties are being purchased for specialized applications and there is increasing interest in the development of rapid and reliable tests.

Wheat varietal identification is becoming increasingly important both in the context of ensuring that the wheat has the appropriate qualities and for purposes of traceability. Such issues have placed greater emphasis on the need for rapid testing so that more recent developments in electrophoresis have been focused on the 'lab-on-a-chip' technology. These are based on microfluidic devices which integrate all of the chemical and processing steps necessary for separating proteins using capillary electrophoresis (Lookhart et al. 2005). Another improvement to the electrophoretic techniques is the automation of varietal identification using pattern-matching software (Bhandari et al. 2005).

Wheat Storage

All the above laboratory tests should be carried out quickly preferably while the lorry, truck or railcar is at the mill, waiting to tip its load in order to avoid the intake of undesirable wheat parcels. The results of the tests should be assessed and a decision made as to whether the wheat meets the requirements of the relevant specification, and if so, into which storage bin it should be put. After the wheat has been tipped but before it reaches the storage bin, it will pass over some preliminary wheat-cleaning equipment consisting of coarse screens and magnets designed to remove the larger impurities in the wheat which may otherwise damage the mill equipment and possibly block the bins charging or discharging.

The art of milling is to produce a consistent final product from a varying raw material. This is achieved through blending, and the process starts in the storage silos where wheat can be segregated into different types. These segregations depend on the type of flour being milled; obviously bread and biscuit types will be kept separate. The wheats may also be segregated by variety or HFN and they will often be separated into different protein bands. By segregating the delivered wheat in this way and then eventually blending it back at controlled levels, a more consistent finished product will be achieved, and milling efficiencies maintained.

The quantity of storage space at the mill can vary widely and is dependent on many factors. In the UK, where mills are sited very near to the wheat-growing areas and road transport is good, mills need only have a very low storage capacity which could be as little as for 1 week's production. In some other countries storage on farms is very limited and the distances involved are much greater, so in these situations mills may contain many months' stocks of wheat. The care of wheat in storage will depend on the length of time it is expected to be there. If the mill has relatively small capacity and a high turnover of wheat there should be no need for any special care, so long as the grain is regularly monitored. However, if the grain is to be kept for long-term storage, then it should be regularly turned bottom to top to help blend it and prevent any hot spots from occurring from localized microbiological activity, and to limit the potential for the development of mycotoxins (de Koe and Juodeikiene 2012).

Mycotoxin Testing

The development of rapid test kits for the detection of mycotoxins has greatly improved food safety and significantly reduced the period of time required for evaluating grains. Many test kits involve the use of enzyme linked immunosorbent assay (ELISA) technology (Salmon et al. 2007) and a wide range of these are now available (Poms 2009).

The Mill Screenroom

From the storage silos wheat will be drawn off and passed through the screenroom to be cleaned. This is commonly a dry cleaning process and is designed to remove a wide range of impurities typically found in wheat. The equipment used relies on five basic principles to achieve this separation:

- Size;
- Specific gravity;
- Shape;

- Magnetism;
- Air resistance.

Size. This is the most basic type of separation, in which the machine generally comprises a double deck system, the top deck being a coarse screen which removes coarse impurities such as string, straw and paper, and allows the wheat and finer impurities to fall through to the second deck. There a finer screen allows smaller impurities such as sand and dust to pass through, and to let the wheat overtail. However, any contaminants which are the same size as wheat will not be removed and a different technique is required to take them out.

Specific gravity. Some cleaning machines rely on the different densities of materials for separation of contaminants from wheat. The wheat will pass onto an inclined oscillating sieve bed and is fluidized by a controlled flow of air up through the sieve. Dense items such as stones fall through the screen onto a lower deck where as a result of the oscillations, they then travel up the deck and overtail into a container. To operate effectively, the machines require a delicate balance between the three variables, air flow, oscillation and angle of inclination.

Shape. Machines that use this principle are commonly called cylinder or disc separators. They work in one of two ways. One type has discs with small pockets cut in them just the right size for small round seeds to fall in. As the discs rotate in the bulk of the wheat the seeds are lifted out and transferred to a separate conveyor. The second type of separating machines has pockets which are just big enough for wheat to fall into, and the wheat is lifted out leaving oats, barley and un-threshed grain behind. Usually these machines are used in tandem to remove both types of impurity.

Magnetism. Plate magnets are situated at strategic points throughout the screenroom to collect any ferrous metal contamination. At this early stage in the process they are used to remove contamination as part of food safety considerations and to protect the mill equipment. Metal detectors may also be part of the mill screenroom machinery as a means of rejecting non-ferrous materials.

Scouring. In some parts of the milling world the grain may be passed into a chamber and subjected to an abrasive treatment with the objective of removing loose dust and dirt. This is achieved by a series of paddles which through the gain outwards where it comes into contact with a wire mesh screen. Thus dry cleaning method has largely replaced water washers in most countries because of their high operating costs (Kent and Evers 1994). Aspiration usually follows scouring. This cleaning process may have some benefits in reducing the microbial load associated with wheat grains but is not able to have any significant impact on microorganisms that may be held within the crease of the grains.

Aspiration using air resistance. Light impurities, such as dust and fine dirt, and those with a large surface area, such as wheat chaff, lend themselves to being removed by a controlled flow of air. The wheat is spread into a wide curtain to expose the maximum surface area and air is drawn through it. Aspiration machines are used in several places throughout the screenroom, as the actual handling of the grain creates dust which needs to be controlled and removed.

Conditioning

The final process which takes place in the screenroom is conditioning of the wheat to prepare it for the milling process itself. Water may be added to the grain to a predetermined level and then left to stand for up to 24 h. The amount of water used, and the standing time vary according to the type of wheat and milling practice. For example, Canadian wheat may be damped to between 16 and 17 % moisture and left for a minimum of 12 h, while a soft English biscuit wheat may only be damped to about 15 % for only 4–7 h. Increasingly there is a tendency for conditioning times for wheat to become shorter, not least because of the limited storage capacity at many modern flour mills.

Conditioning is a critical stage in the milling process. Modern damping systems are fully automated, with moisture levels being continually monitored to maintain a constant level of water addition. The purpose of the conditioning is to aid the removal of the bran layers from the endosperm. By keeping the bran layers damp they will detach more easily and stay in larger pieces which aids their removal from the endosperm through the rest of the milling process. Poor conditioning of wheat will mean that the bran layers break into small pieces which are difficult to remove and give the resulting flour a specky appearance and contribute to darker coloured flours and higher ash contents. Poor conditioning often leads to a lowering of the extraction rate if values for colour or ash exceed specified levels.

The moisture levels used during conditioning, especially for the harder wheats, are not maintained through to the finished flour where high flour moisture content would cause rapid deterioration during storage. During the conditioning process a moisture gradient is developed within the cross-section of individual grains, high on the outside and lower in the centre. The removal of the bran, together with the heat generated within the milling process, brings the moisture of a typical white flour back within the range of 13.0–14.5 %. After being fully cleaned and conditioned, the wheat is now ready for the milling operation itself.

Grain Sorting

The development of imaging technology combined with increased computing power and faster computing speeds has enabled the development of technologies which have significant potential for the wheat milling and many other grain, pulse and kernel-based industries. Imaging technology is now available which can be placed in-line with wheat processing equipment which can be combined with high-speed sorting technology to remove unwanted grains and improve the purity of the feed to the mill (e.g. Sortex A optical sorters from Buhler 2014). The technology can not only enable the removal of shrivelled and small grains but also those which may have colour defects which are indicative of other unwanted features; for example, grains with blemished commonly referred to as 'blackpoint' which are often associated with the presence of fungal diseases (Williams et al. 2009).

De-branning and the Flour Milling Process

Milling systems are becoming increasingly refined. One technique that is being increasingly used in flour milling is the removal of some of the outer bran layers of the wheat before it enters the break system. Commonly referred to as 'de-branning' it is based on the 'pearling' process commonly used in the preparation of rice kernels. The presence of the crease in the wheat grain means that pearling is more difficult to achieve than is the case with rice. The de-branning process does not require the classic conditioning stage, instead the bran layers are carefully removed in a two-stage machine abrasive process followed by inter-particle friction (Satake 1990; Campbell et al. 2012). Bran removal is very tightly controlled to suit the ash content of the finished product. The endosperm is not disrupted during the process, so the problem of separating bran powder from the flour does not exist to the same degree as it does in the standard flour milling process. The pearling stage is closely followed by a 'hydrating' section used to control the level of moisture in the finished flour. The hydration time is significantly reduced to between 30 min and 2 h, and is only necessary to replace moisture loss during the milling process. This shorter time means that this new process can quickly respond to the moisture content of the finished flour, and a control loop can be set up to maintain the level far more accurately than with current conditioning systems. One of the advantages claimed for using de-branning is a reduction in the level of microbial contamination (Pandiella et al. 2005). This occurs because the microorganisms which naturally contaminate wheat are associated with the wheat hairs and bran layers. However, even de-branning cannot reach those microorganisms which are embedded in the crease of the wheat.

The Progress of Wheat Through the Mill

From the early days of the twentieth century, flour milling has developed into a complex network of machines all doing a very specific job; however, the basic principle of the process has changed very little in the last 150 years or so. In essence the wheat is ground between many pairs of cast-iron or steel rolls, and the products from the grinding process (mill stocks) are separated on a sieve into various sizes and quality fractions which are then re-ground. There is no such thing as a standard flour mill because like bakeries, the equipment used in the flour milling process is

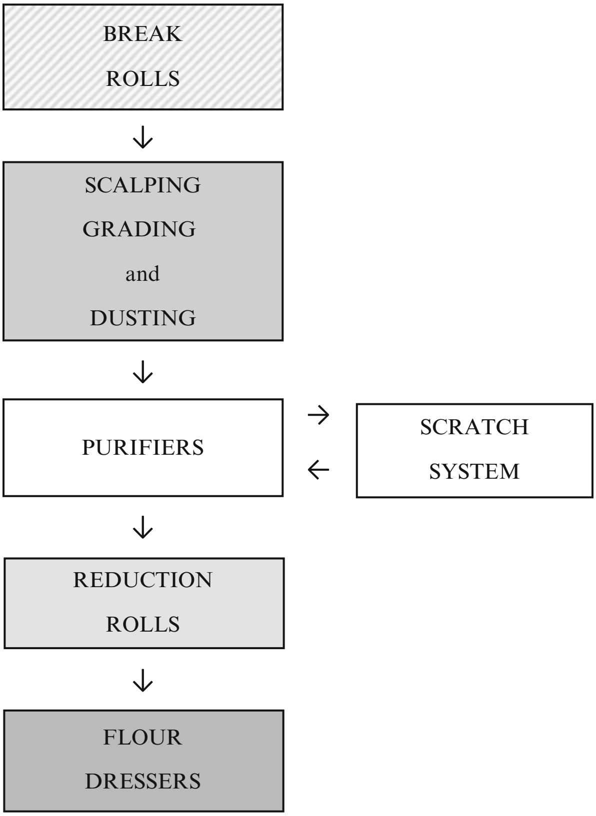


Fig. 12.2 Schematic of a flour milling process

continually evolving and varies according to local requirements. This is particularly true of the control systems being used to set and run a mill. Much of the need to manually adjust mill settings has been replaced by in-line monitoring systems and there has been a reduction in the energy requirements; flour milling like baking, is an energy hungry process.

The modern flour milling process can be separated into six very distinct areas (Fig. 12.2):

1. The break system—the first grinding stages for the wheat;
2. Scalping, grading, dusting—the separation of the ground materials after each of the break rolls;
3. The scratch system—the final removal of bran from the system, although sizing systems are more commonly used in modern plants;
4. Purifiers—the cleaning up of semolina stocks (endosperm fragments) by grading and aspiration to remove bran fragments;
5. The reduction system—the gradual reduction of semolina to flour;
6. Flour dressing—the separation of flour from the other materials (mainly bran).

The flour finally produced for the baker does not necessarily pass through every one of these stages. After each section some flour is created and will be removed for blending, leaving the remaining stocks to continue through for further processing. Thus, when a baker sees a white flour it is actually a composite of many white flours which have been separated at different stages of the milling process and then later blended together to deliver a single, straight-run flour (see below).

Break System

The rolls which go to make the break system are the first of the grinding operations, and consist of a series three to five, but usually four pairs of fluted rolls designed to break the grain open and extract as much of the endosperm as possible for the production of white flour. At this stage the endosperm will be in the form of coarse particles known as semolina, and must be separated from the individual grains with a minimum amount of disintegration of the bran. This is achieved by a combination of the flutes of the roll surfaces, which are cut on a slight spiral, and a speed differential between the rolls of the order of 2:1, which apply a scissors-type action to the wheat grain (first break) and subsequent fragments (second to fifth breaks). The designs of the flutes have been determined by experience, and get finer as the intermediate products pass from the first break rolls to the fourth or fifth. After each set of rolls the products pass to a sifter for separation into a series of sub-fractions before going on to the next part of the process. Even at this early stage in the mill process some flour will be produced, either released from along fracture lines of the endosperm or due to attrition of the different particles. This will be sieved out and bypass the rest of the process. At this stage the amounts will be small since it is not the aim of the break system to produce finished flour.

Scratch System and Bran Finishers

The rolls used in this part of the milling process are more finely fluted rolls than in the break system. They are designed to remove the last fragments of endosperm from the smallest bran fragments. Stocks are usually transferred to the ‘scratch’ system from the purifiers where bran-rich materials have been separated out. In some mills special bran finishers are installed after the third, fourth or even fifth break roll to ‘dust off’ the last remaining flour from these bran stocks. This scratch system helps to increase the extraction rate, but the flours produced are of a low grade and have poor functionality in breadmaking. A variation of the scratch system is called the ‘sizing’ system used in more modern mills where throughputs are higher, causing large variations in the feed to the first part of the reduction rolls. To even this out the normal coarse semolina from the first and second breaks are fed through a finely fluted sizing roll. This process gauges the semolina to a more uniform particle size and also flattens the germ allowing it to be separated out, by sieving.

The germ is rich in oils and vitamins and has a number of potential uses; not all of them associated with baking. The germ may be used to produce specially fortified breads but being rich in oil, tends to go rancid within a few months. If it is necessary to keep germ-enriched flours for any length of time, the germ may be heat-treated to inhibit enzymic activity and thus rancidity.

Scalping, Grading and Dusting

These terms describe the separation of the stocks after the action of each of the break rolls, and which take place inside the multi-sectioned oscillating sieves. Scalping is the separation of the coarse overtails, generally bran fragments with some endosperm attached, which can then be passed on to the next reduction roll in the system. Materials passing through of the scalping sieve can be divided into coarse and fine semolina in a process known as grading. These fractions will pass straight to the purification system, while the flour that has been produced will be removed and transferred to the flour collection system. Bran and the majority of the wheat-feed (mainly small particles of bran) will be removed from the system after the final break roll sifters.

Purifiers

The main aim of the purifiers is to clean or ‘purify’ the semolina stocks coming from the break sifters. Typically, a purifier is a long oscillating sieve-bed, mounted at an incline above various receiving hoppers. Air is drawn up through the stocks being sieved which, together with the reciprocating action, stratifies the stocks and lifts out fine bran. The air flow can vary as the products pass down the length of the machine, leaving the purified product to fall into the hoppers beneath them to make their way into the reduction system. A well-set purifier is important in supplying cleaned semolina to the reduction system in order to improve the efficiency of the latter. White flour with bran specks will produce unattractive bakery products and have a lower protein quality resulting in a reduced flour performance in breadmaking.

Reduction System

This is the final grinding stage in the flour production process when the cleaned semolina stocks are reduced down to the finished flour by a series of up to 12 pairs of roller mills. Reduction rolls have a smooth surfaces and run with a reduced speed differential between the individual rolls in the pairs. The first section of reduction rolls will generally be dealing with the cleaner semolina stocks, mostly from the first and second break sifters, and will therefore be producing the whitest flours with the best functionality for breadmaking. The middle section deals with the tailings from the first section and also the poorer quality stocks from the later break purifiers. The final two or three rolls deal with the stocks overtailing the first two sections, and will be producing lower quality flours.

The set-up and performance of the reduction system in a flour mill has a significant effect on the water absorption capacity of the flour. There are three key factors in a flour specification which can have a direct effect on the water absorption:

- Moisture content;
- Protein content;
- Level of starch damage.

These three factors, together with the pentosan content (Chap. 11), enable the water absorption to be calculated with some accuracy though the tendency is to continue to measure this with a suitable method based on mixing a dough to a standard consistency. Given that the protein and moisture are predetermined by the specification and that the pentosan content is not a normal flour test, the major influence on water absorption comes therefore from the starch damage. In the milling process, damage to the starch granules present in the flour is achieved by in the reduction system which physically disrupts the starch grains and allows access to more sites on the starch chains for the water to bond. Grinding hard can also have an effect on the particle size of flour. Some flours, specifically those used for dusting, need to be coarse and free flowing so that they do not clump and block feeders. By reducing the degree of grinding, the mill can produce a flour which meets these particular requirements.

Flour Dressing

As in the break system, each pair of reduction rolls is followed by a sifter making between three and five separations. Flour is removed and the remaining stocks are graded between the reduction rolls which follow. Towards the end of the system the flour removed is of poorer baking quality. The overtails pass out of the system into the wheatfeed bin. The operation of this sifting system is critical to maintaining the efficiency of the flour mill and can be hindered by the action of the reduction rolls on the semolina stocks. As mentioned earlier, the pairs of reduction rolls are running at similar speeds, and so have a tendency to flatten the semolina particles and produce small flakes. If the flakes are passed to the sifters, the sieving action can be very inefficient and too much material overtails the system. To prevent this from happening, flake disrupters are installed above most reduction rolls. These machines are made up of two metal discs, held apart by short pins, mounted inside a case and driven by a high-speed motor at approximately 3000 rpm. Flour stocks pass into the centre of the discs and are thrown outwards through the pins by the centrifugal force, breaking up any flakes on their way through.

Table 12.1 Analytical data from machine flours (Cauvain et al. 1983)

Machine code	% Final flour	Protein content (% as-is)	Damaged starch (FU)	Ash (%)	CBP water absorption (%)	CBP 400 g bread volume (ml)
1 BK	3.3	11.7	11	0.66	55.0	1451
2 BK	2.1	13.5	5	0.62	56.4	1419
3 BK	1.7	15.3	4	0.54	57.5	1438
3 BKF	0.9	14.1	9	0.70	54.6	1372
4 BK	4.4	12.9	17	0.70	58.2	1425
BMR	8.7	11.7	16	0.55	56.6	1527
TU	2.9	14.2	23	1.11	58.5	1256
A	23.5	10.5	29	0.37	60.7	1446
B	20.4	10.5	29	0.37	61.8	1398
B2	0.8	10.2	33	0.56	61.4	1438
C	16.6	10.8	24	0.43	61.8	1470
D	4.6	10.6	35	0.56	63.6	1358
E	1.6	11.9	28	0.68	62.9	1313
F	0.5	13.1	28	1.11	60.4	1190
G	2.4	11.6	26	1.00	57.5	1204
H	1.2	12.9	17	1.05	60.7	1214
J	0.6	11.7	30	1.29	57.9	987
X	3.7	10.2	18	0.41	56.4	1522
Straight run	100.0	11.1	26	0.64	60.7	1476

1 BK–4 BK represent the break system
A–J represent the reduction system

At the end of the flour dressing process all the flours from the various machines are brought together and blended to produce what is referred to as a ‘straight run’ flour. This is the normal white flour supplied to the majority of customers, and accounts for between 76 and 78 % of the initial wheat mass. This figure is referred to as the ‘extraction rate’ and is an indication of the mill efficiency. An example of a straight run white flour is given in Table 12.1 which indicates the proportion of each component of the flour and a selection of the analytical for each machine flour. It must be emphasized that the data presented are indicative of what might be seen in a flour mill; specific data will vary widely depending on mill set up, operation and required flour specification. However, such data are useful for understanding how the principles of wheat flour milling operate. For example, the much greater proportion of the white flour coming from the reduction system is very evident by comparison with the break system. Indeed reduction rolls A, B and C account for some 60 % of the final flour output. Also evident is the production of high levels of damaged starch in the reduction system. The higher levels of protein are evident with flours from the break rolls but so too are higher ash levels reflecting the higher level of bran contamination.

If required by the customer, the miller can be more selective with the streams of flour being produced and make a ‘patent’ flour. This will use only the high-grade streams with the whiter colour, generally from the first section of the reduction system. In this case the flour protein will be slightly lower due to the naturally occurring protein gradient in the wheat grain, i.e. the outer layers have a higher protein content, but the quality is not quite as good. A patent flour would have an extraction rate of approximately 60 % and is more costly for the baker. The dark flour not used in the manufacture of a patent flour is referred to as ‘low-grade’. While not suitable for many bakery products they may be included in flours destined for malted breads, speciality rye breads, and some types of boiled pie paste where the poor colour can actually be used to advantage.

At the end of the milling process there will be a range of different products:

- Straight run white flour (or patent and low-grade flours);
- Coarse and fine wheat brans for use as an ingredient in many bakery products, health foods and breakfast cereals;
- Wheatfeed used as an animal feed and containing the finest brans;
- Wheatgerm which may be sold separately.

Wholemeal, Brown and Enriched Flours

Much of the above discussion has focussed on the production of white flour. This is because the majority of wheat flours manufactured throughout the world are composed mainly of the wheat endosperm. Large quantities of non-white flour are manufactured with descriptors and legislative requirements which vary significantly in different locales. The following discussion of non-white flour milling will concentrate on the principles applied in the flour mill, readers are advised to check local legislation and regulations as these may affect the detailed manner in which non-white flours are manufactured in the mill and offered to the baker. In many parts of the world the manufacture of wholemeal flour has to be based on delivery of a final flour which contains 100 % of the wheat grains with the various components in largely the same proportions of the starting grains. Some allowance may be made for the removal of extraneous matter in the delivered grain but essentially the milling process for wheat grains destined for the manufacture of wholemeal flour reach the end of the process with an unchanged composition.

In its simplest form wholemeal flour is produced by grinding grains between a pair of stones and the resultant material is commonly referred to as ‘stoneground’ flour. However, the performance characteristics of the final flour can be significantly improved by basing the manufacture of wholemeal flour on the roller milling process. In this case the miller will take the various ‘white’ flours which comprise a straight run flour and blend back the germ and bran fractions in the proportions that they were present in the initial grain. This approach delivers improved functionality from the endosperm and reduces the negative effects associated with the production of fine bran. Cauvain (1987) showed that coarse bran can give a good visual effect both in the bread crumb and on the crust, but if there is too much coarse bran present in the flour it can result in an open and unattractive crumb structure. Fine bran can have a deadening effect on the bread, resulting in a bland, small loaf with a dull grey crumb.

Brown, bran and germ enriched flours can be based on the manufacture of a suitable white base flour and the addition of various levels and forms of bran and germ. In some cases the bran, and especially the germ, may be heat treated to reduce the potential risk associated with rancidity during storage.

Self-raising Flours

A combination of sodium bicarbonate together with a suitable acid ingredient will produce a flour for a variety of uses, including the manufacture of batters, cakes and scones and a few breads. By varying the acid ingredient, the point in the process when the carbon dioxide is evolved can be varied. For example, if monocalcium phosphate is used then 60 % of the carbon dioxide will be generated at the mixing stage and 40 % during baking. If this ingredient is changed to sodium aluminum phosphate, then this can be changed to 30 % at the mixing stage and 70 % during baking. The requirement for heat to be applied before the majority of the carbon dioxide is liberated can be useful if the product is required to stand before baking or if an extended shelf life is required in the flour. For a more detailed discussion of the addition of baking powder components to flour the reader is referred elsewhere (e.g. Street 1991).

Malted Grain and Multi-seed Flours

The addition of malted grains, either kibbled or flaked, together with additional malt flours, either diastatic or non-diastatic (or both), can produce a very attractive bread with exceptional flavour characteristics. In some cases millers may supply a ready blended mix of wheat flour and other seeds to deliver a more convenient product for bakers to use.

Storage and Packing

From the mill, white flour will pass through a final redresser before bulk storage. The final redresser will be a fine sieve of about 300 μm mesh. The sieve here is used as a precaution should one of the many other sieves in the mill burst.

The overtails will be monitored on a regular basis to check for this particular problem. Bulk storage bins can be made from either wood, concrete or steel, depending on a balance between personal preference, materials available, product safety and price. Early bins were made of wood, which at the time was a good material and offered a degree of insulation which helped prevent condensation. Concrete can be used but such bins are liable to crack, are very heavy and require deep foundations. Both these materials have the disadvantage that pieces can break off and contaminate the flour, which helps to confirm steel bins as the most popular choice for modern flour mills. These are cheaper, do not crack like concrete, are lighter and easier to install, and if required can be dismantled and re-sited. Bin cross-sections may be either square or round. Round bins are stronger but take up more space for a given capacity. Square bins need corrugated sides to give added strength, but have the advantage that there is no dead space between adjoining bins where infestation can build up.

From bulk storage the flour is transferred for either bulk delivery or packing. Commonly the flour will pass through a redresser to check that is has not been contaminated with foreign material or hard lumps of flour. Packing covers a range of sizes depending on final usage, from 1 kg for domestic use up to 1 tonne tote bags for medium-sized bakeries. Paper sacks are commonly used for smaller quantities of flour. Bulk tankers can make deliveries from 5 tonnes to a maximum defined by local transport weight regulations. The smaller deliveries will use specialized tankers which either have compartments for different flours or have one flour that can be metered accurately to different customers. These smaller bulk deliveries do not offer the same advantages in terms of cost benefit as those derived from a full tanker delivery, although they do significantly reduce the amount of packaging to be disposed of by the baker.

Food Safety and Product Protection

The consumer's requirement for confidence in the safety and wholesomeness of the foods that they eat stretches back to the primary ingredient suppliers. Growers now understand that they have a role to play in food safety and the dialogue between millers and farmers is increasingly a strong one. Customer concerns about possible contaminants are usually addressed by applying Hazard Analysis Critical Control Point (HACCP) principles to flour milling.

Possible contaminants of flour can be broken down into three basic categories:

- Foreign bodies;
- Chemical;
- Biological.

Foreign Bodies

These are probably the most common problem with flour but potentially the easiest to deal with. Typical contaminants would be those associated with the milling process and include pieces of hardened flour from blow-lines and bins, sifter wire or nylon, pieces from sieve cleaners and cotton fibres. The flow in a flour mill has the benefit that it incorporates a collection of sieves at strategic points throughout the process. Some of these are process sieves to separate the different stocks within the mill. However, others such as the final redresser and the redressers after bulk storage, are critical for monitoring and ensuring the safety of the finished product. Overtails of these sieves will be checked at relevant times and the findings recorded. While small amounts of bran and hardened flour will always be found, increases beyond the norm are indications of a possible problem and indicate the need for corrective action. The same principles should be applied to metal detectors and magnets. Magnets have been used in flour milling for many years to protect milling equipment from damage and protect the final product. Increasingly metal detectors are being used to remove materials as small as 1 mm in size.

Chemical Contaminants

There are two main areas of concern under this heading: pesticide residues and taints. Recent concerns about the effect of these chemicals on the environment has resulted in tight controls being used to minimize their use. All chemicals used on agricultural products are regulated by laws and recommended codes of practice, e.g. EU and CODEX, which define their maximum residue limits (MRLs). It is the farmer's responsibility to ensure that these levels are not exceeded; however, millers will check relevant agricultural practices by setting up regular checks to confirm the safety of the ingredients they are using. In the UK a 'Pesticide Passport System' (HGCA 2011) has been introduced to record what type and level of pesticides has been used on a particular load of wheat. Taints are far more difficult to track down. The very nature of flour lends itself to absorbing taints and as a general precaution it should never be stored near strong-smelling ingredients, such as spices.

Biological Contaminants

Considered under this heading are microbiological contamination, e.g. *Salmonella* and *E. coli*, and product infestation. The microbiology of wheat flour cannot be controlled to any significant degree by the normal processes of flour milling, other than to a limited extent by de-branning (see above). Millers commonly produce their flours using good manufacturing practice (GMP) to reduce risks of contamination and will develop cleaning schedules for all areas, especially high-risk areas such as wheat damping and conditioning equipment, so that cross-contamination can be significantly reduced. In all cases the wheat milling operation starts with a raw agricultural material which is processed to a flour. From a HACCP point of view, flour should always be treated as microbiologically dirty and should not be eaten raw or come into contact with finished bakery products. In most situations this is not a problem because most food products containing flour are baked before consumption. There are one or two examples of flour confectionery where this is not the case, and in these situations heat-treated flour or flour from steam-treated wheat can be used. However, all forms of heat treatment denature the gluten and this makes it unacceptable for the production of bread and fermented products.

A particular area of concern is the potential presence of mycotoxins such as aflatoxin and ochratoxin from specific toxigenic fungi. It is well documented that most foods are prone to fungal growth at some stage during production, processing and storage (Frisvad and Samson 1992). These fungi may well be killed or removed during processing; however, the toxins which have been produced will remain in the final product. The only form of control is to avoid using the conditions under which the moulds concerned will flourish. With levels as low as 4 ppb final flour being quoted in specifications there is very little room for error, and with relatively limited historical information and variable environmental inputs, this is an area which continues to tax millers, grain merchants and farmers.

Control of infestation within the mill takes several forms. Inspection of the raw material at intake can prevent infestation entering the building, and cleaning schedules and regular hygiene inspections can prevent the build-up of material which could form the nucleus for any infestation outbreak. Spot spraying of any problem areas can help keep the problem under control. Historically annual fumigation in a flour mill was carried out using with methyl bromide in the late spring in temperate areas of the world when insect activity is just beginning to build up. Increasingly the use of methyl bromide is being reduced but as it helps control deep-seated activity it is not proving easy to rely on alternative methods. The problem is that methyl bromide was confirmed as an ozone-depleter and the effect of the Montreal Protocol (1993) meant that alternatives needed to be sought and implemented. The application of heat has been suggested (Dosland 1995) but it is more expensive and lacks the penetrating effect of methyl bromide to all parts of the mill. Other gaseous treatments include sulphuryl fluoride and a combination of phosphine with carbon dioxide. The fumigation of flour mills is a specialist business.

Many mills employ enloteters which are in-line flake disrupters used after the reduction rolls and they have the effect of breaking up any insects and their eggs. However, these cannot be relied on exclusively to deliver ‘clean’ flour as they leave the insect fragments in the flour, and this itself can cause customers problems, especially in parts of the world where the filth test (AOAC 1990), the number of rodent hairs and insect fragments in a sample of flour, is used as a quality standard. With white flours having a potential shelf-life of up to 12 months, it is important that millers do all in their power to prevent contamination of their product.

Controlling Flour Quality and Specification

The corner stones of flour quality are ‘fitness for purpose’ and ‘consistency’. Flour is the major raw material in bread and fermented goods and needs to be of the same quality all of the time, so that the bakers can, in turn, achieve high manufacturing efficiencies and provide their customers with a product of consistent quality. The problem for millers is that flour is used in a wide variety of bakery applications and they have to find a way of controlling quality for all of them, even though the basic raw material is variable. This is achieved using two main techniques:

- By blending either the wheat, the flour, or both;
- By the addition of selected additives.

Gristing Versus Blending

The start of the quality process is the blending of wheats or the recipe known to the miller as the ‘wheat grist’. Based on the type of flour required and its specification, the miller will decide which mixture of wheats should be used in the grist. At intake the individual wheat parcels will have been segregated into a number of different types, such as biscuit, bread, high protein or low protein. The grist for a particular flour will have been predetermined by a variety of methods, but generally it will be based on the miller’s experience of the character of performance characteristics of different wheat types and a knowledge of the customer’s processes. For bread flours the grist will be blended to a consistent protein level that will be up to 1 % higher than that of the finished flour to allow for the protein drop between wheat and flour due to the higher levels of less functional protein in the bran layers than in the endosperm. Where possible, the wheat protein can be gristed to a lower level to allow for the addition of dried vital wheat gluten. This material is very useful especially in seasons when wheat proteins are low because it can help maintain the flour protein at the required level (Cauvain 2003). Another advantage of adding dried gluten is that with the ability to monitor protein continuously on-line using near-infrared (NIR) spectroscopy, a control loop can be set up to feed in the dried gluten thereby giving very tight control of protein levels (Maris et al. 1990).

Typical levels of addition will contribute less than 2 % of the final flour protein content. Since many dry glutens have around 70 % protein that equates to about 3 % weight for weight addition to the base flour. Dry gluten absorbs a slightly greater weight of water than wheat flour which means that gluten—supplemented flour water absorptions will be higher than anticipated for their protein content. A potential problem using dried gluten is that it does affect to some degree the hydration time of the flour and the rheological properties of the dough. Depending on the amount used the dried gluten component can continue to hydrate after mixing, giving a tighter dough than is required and causing problems with moulding. The gluten in the mixed dough will also appear more elastic and tougher, but this may help maintain the shape of oven-bottom breads.

The protein content of bread flours can vary widely according to the type of bread being manufactured, the breadmaking method being employed and the desired characteristics in the final product. Typically, at the lower end of the range would be French flours for baguette from 9.5 to 11.0 % (14 % moisture) using selected French grown wheats, rising up through 10.5–12 % for CBP sandwich-type breads, to 11.0–12 % for general-purpose bakers' flours and, finally, 12.5 % and above for speciality breads (Chap. 2).

Once the chosen grist is running through the mill, the miller can affect characteristics such as flour water absorption by adjusting the amount of starch damage created in the reduction system, and flour colour by the amount of tail-end (low-grade, high ash) flours allowed into the final blend. Patent flours, i.e. flours with an exceptionally white colour, are particularly good for breadmaking. They give a good crumb colour and, although their protein content might be slightly lower than a normal straight run flour, their quality and baking performance are far superior. Unfortunately, the cost of these flours generally makes them less commercially attractive.

Blending wheats prior to milling is a very popular way of producing flours but it does have some disadvantages. Each wheat in a grist will have its own peculiar milling characteristics, depending on its variety or source, for example grain size, shape, hardness, moisture content, protein quantity and quality. They all affect the way the grain behaves through the mill, so that if the grains are blended before milling, the mill settings will have to be a compromise between the various milling characteristics of the wheats. However, if the wheats are milled individually, for example by variety or type, and then the flours produced are blended, millers can be more accurate with the settings of the roller mills and the purifiers, and so maximize the quality from each wheat. Each individual flour milled can then be fully analysed before blending is carried out, with the result that a more consistent flour is produced. In its most basic form the flours for blending are metered together volumetrically using variable-speed discharges on the bottom of the bins. With more sophisticated batch blending ribbon-type or similar mixers are used and the flours weighed into the mixer along with any other additions. A flour blending system can give better control of finished products and more accurate application of any additives or treatments.

Flour Treatments for Breadmaking

Various flour treatment and additions of functional ingredients are the final tool available to millers to improve the performance and consistency of their products. Over recent years the number of additives being used by the miller has declined significantly, in part because of safety concerns about the use of chemicals in food and in part because of the need for bakers to better understand the optimum formulation requirements for a given bakery. In practice many millers around the world are only left with ascorbic acid and various enzymes as methods of controlling the performance of their flours (Chap. 3). Other nutritional additions may be made to meet with legislative requirements for nutrition in various countries (e.g. Bread and Flour Regulations UK, 1995) or to meet the supply requirements for a particular market sector.

Ascorbic Acid

It has been known for around 70 years that ascorbic acid, chemically a reducing agent, can be used as an oxidizing bread improver (Melville and Shattock 1938). During mixing the atmospheric oxygen converts the ascorbic acid to dehydroascorbic acid, which is the oxidizing agent. Its effect on the gluten is to reduce extensibility and increase elasticity, giving better shape and finer texture to the finished breads. It is added at low levels by flour millers to provide improved flour performance in those breadmaking situations where a separate improver addition will not be made in the bakery (see Chap. 2). If a separate improver addition is being made then usually the additional contribution from the flour is too low to have a major effect on bread quality, though this does in part, depend on the breadmaking method being used. As noted in Chap. 2, the use of potassium bromate is still permitted in some parts of the world and low levels of this oxidant may be added at the mill.

Enzymes

The addition of enzyme-active materials to breadmaking flours in the mill is now more widely practiced and can be problematical for the baker because their use may not be declared. Their use is described in more detail in Chap. 3 and elsewhere (Kornbrust et al. 2012). The three types of enzymes most commonly used by millers to supplement flours are:

- Amylases;
- Proteases;
- Hemicellulases (or xylanases).

Amylases. One of the most common techniques used by bakers has been to include a small amount of malt flour in the bread mix. This would have contained large amounts of cereal *alpha*-amylase which would break the damaged starch down to dextrins, which in turn would be broken down by the *beta*-amylases into maltose, a useful yeast food. Malt flour was also used by the miller to improve flour performance, especially when the HFN was particularly high. However, it was known that at excessive levels of addition, bread crumb becomes sticky and difficult to slice. This is caused by the *beta*-amylase being deactivated much earlier in the baking process than the *alpha*-amylase, which continues working until approximately 75 °C (167 °F) and produces an excess of sticky dextrins (Chamberlain et al. 1977). In the early 1970s fungal amylases were introduced, which were a much more controlled ingredient with the added benefit that they are deactivated earlier in the baking process (Chap. 3). This means that they can be used without creating stickiness problems, with additional benefits including a finer, whiter texture, better volume and an apparent improvement in the shelf life of the bread (Cauvain and Chamberlain 1988).

Protease. The group of enzymes included under this heading are generally used where large quantities of hard wheats are included in the milling grist, e.g. North American. They help to reduce the strength of the dough (its 'buckiness') and so improve handling and product texture, but they must be used with discretion to avoid a complete breakdown of the dough structure. A more common use of proteases would be in the production of biscuits and wafers where weaker proteins are more desirable and yet some degree of protein functionality is still required (Wade 1995).

Hemicellulases (*xylanases*). The use of hemicellulases in breadmaking is a more recent introduction. In general, they break down in a controlled manner the pentosan component of the hemicellulose. This action continues through the mixing, fermentation and early baking stages, giving a soft but not sticky dough and which yields bread with improved volume and texture. They are useful in all flours, but of particular benefit in flours which contain high percentages of hemicellulose, such as brown, wholemeal (wholewheat) and rye flours and meals.

Nutritional Additions

Bread has always been seen as a staple food, and as such has been well regulated to prevent adulteration and to protect the consumer. Fortification of flour because of its role as a major ingredient is seen as a method of ensuring that populations can receive relevant minerals and vitamins that might be lacking in some diets (Rosell 2012). By way of example since the 1940s all flours in the UK, with the exception of wholemeal, have contained the following:

- Calcium carbonate to provide calcium ions;
- A source of iron;
- Thiamine;
- Nicotinic acid.

Even the last amendment of the UK Bread and Flour Regulations (1995) has retained this type of fortification. The future may actually bring an increase in the addition of nutrients to flour, either in the mill or the bakery with a move towards 'functional foods', i.e. foods which can make a positive contribution to human health through their consumption. As an example, folic acid, which helps prevent neural tube defects in unborn children (Rosell 2012), has appeared in breads being offered to consumers around the world.

Flour Testing Methods

Millers have a range of tests available to determine values for the most important performance specifications for a particular flour. Of these the measurement of protein quality presents the greatest challenge with different pieces of equipment being preferred in different countries. For a comprehensive discussion of the different methods which might be used to evaluate flour the reader is referred elsewhere (e.g. Cauvain and Young 2009a). It is also worth noting that methods are constantly being updated and new methods developed.

Protein and Moisture Content

These are two of the most important parameters in flour, and are generally measured during production using an NIR analyser; this is by far the most common piece of testing equipment in flour mill laboratories (Cauvain and Young 2009a). It is versatile and rapid, conducting a range of tests depending on the calibration used, such as protein and moisture, starch damage, water absorption and colour, in less than 30 s. However, with speed of measurement and the relative imprecision of the reference methods (e.g. colour) some accuracy is lost, and the NIR analyser is most appropriate for the main parameters of protein and moisture. To maintain their accuracy, NIR instruments must be calibrated at regular intervals by comparing them with national and international, standard methods. For protein content this is normally the Kjeldahl acid digestion method using sulphuric acid in the presence of a catalyst. The nitrogen figure produced is then converted to a protein value using the Kjeldahl factors as follows:

Wheat bran	6.31
Other wheat products	5.70
Other foods	6.25

The Kjeldahl method has now largely been replaced by the Dumas method, a much safer system based on using combustion in the presence of oxygen (AACC Method 46–30, 1995). It is as accurate as the Kjeldahl method, and much quicker; and is fast enough to be used as a quality assurance test during the milling operation, but requires more skill to operate than the NIR analyser.

In many countries protein levels are declared on an ‘as is’ basis, i.e. as a percentage of all the flour constituents including the moisture. While this has certain advantages, it relies on the moisture content always being the same, otherwise it could appear that the protein content is varying. For example, a flour measured at three different moisture contents would give the following results:

	Protein (%)
On a dry matter basis (dmb)	10.0
The same flour with a moisture of 8 %	9.3
The same flour with a moisture of 15 %	8.7

It is therefore important that when comparing flour specifications from different countries that the protein content is quoted along with the moisture content and ideal practice is to convert all protein contents to the same moisture basis to the same moisture content or use a dry matter basis.

Moisture determination on the NIR analyser needs to be calibrated to an oven method, typically 130 °C (266 °F) for 90 min and 2 h for ground wheat. This test should be one of the simplest to carry out, but it can prove difficult to obtain consistent results especially when comparing results from different laboratories. This is not necessarily due to problems with the test method or the operatives; it is more likely that the pneumatic handling causes variations in the flour. Throughout the mill, during bulk delivery and also on customers' premises, flour is moved using either negative or positive air pressure. The air movement itself is sufficient to give a drying effect; however, when positive pressure is used, the increase in air temperature due to compression can enhance this effect. It is possible for flour to increase in temperature by up to 5 °C (9 °F) when blown from one bin to another. In this type of situation flour moisture can easily drop by half a percentage point (0.5 %), which is sufficient to cause apparent changes in flour specification as received in the bakery.

Ash, Flour Colour and Bran Specks

Historically the measurement of ash and flour colour were used to assess the level of bran particles present in white flour and the potential negative impact on bread volume. Generally the whiter the flour the lower the ash and, the better the breadmaking properties of the flour (Cauvain et al. 1983, 1985). This fact is recognized in many countries, where the maximum ash content of soft wheat flours (soft milling and suitable for breadmaking as compared with harder milling durum wheat) is defined in law. For example, in Italy there are three main categories, with the ash levels defined on a dry solids basis:

Flour type OO = 0.50 %
Flour type O = 0.65 %
Flour type 1 = 0.80 %

Unfortunately, in countries such as the UK, where flour is fortified with minerals, the ash content appears unreasonably high and cannot be used as a direct measure of flour quality. This fact led to the introduction of a method which measures the reflection of light in the 530 nm wavelength region from the surface of a flour and water slurry contained in a glass cell in a Kent Jones Colour Grader (Cauvain 2009). The output is known as either the flour grade colour (FGC) or the grade colour figure (GCF). The measured value is influenced by background endosperm colour which depends on the type of wheat in the grist, and the particular crop year.

Grade colour is not a measure of the visual appearance of the flour. Two samples of flour that can look completely different may give the same grade colour value. Increasingly there is a move to using Tristimulus measurement to describe flour colour. Typically the notation is based on the L, a, b scale with L being a measure of whiteness on the scale of 0 (black) to 100 (white), a being an indicator of redness (with a+ being red and a− being green) and b an indicator of yellowness (with b+ being yellow and b− being blue) (Cauvain 2009).

'Specky' flour, i.e. flour contaminated with very small but visible pieces of bran, is not readily picked up using the flour colour grader test, and in the past its detection has relied on a visual inspection by millers. Using the advances in image analysis, new methods to test the bran content of flour have recently been introduced. For example, the 'Branscan' is designed for on- or off-line use. A sample of flour is compressed against a transparent window and a video camera with a PC-based image analysis system is used to calculate the number of bran specks. In the laboratory this is carried out by a technician but in the on-line system the process is completely automatic with the results being displayed on a graph with both the number and total area covered by the bran expressed as a percentage (Evers 1993). This method is unaffected by variations in endosperm colour and composition, and can be set up to alarm when a specific figure has been exceeded in the mill.

Water Absorption

Water absorption is a well-used term in flour technology, but means different things to different people. Bakers mixing batters will be adding more water to their products than when they make bread doughs, which in turn will be more than for biscuit doughs. Even within a particular product group, the recipe and process used will affect the amount of water added. Thus for quality control and comparative testing a water absorption test has to eliminate these variations and deal with just flour and water. The dough must also have a predefined, 'optimum' viscosity so that it can at least provide a value that is reproducible.

A common example of a test which has become the standard in the milling industry is the Brabender Farinograph though other variants are available (Cauvain and Young 2009a). This type of machine measures and records the mixing characteristics of a dough made from just flour and water, and continues to record the properties as the dough develops to its maximum viscosity and until it starts to break down. The operator is required to add sufficient water to the flour to produce a dough with the maximum viscosity on the 500 line (600 for most breadmaking flours in the UK). This may take two or three attempts, but once done, the machine is allowed to run to form the characteristic Farinograph curve. The water absorption is the amount of water added to the flour to achieve a given viscosity and is conveniently recorded in percentage terms. The Farinograph itself also gives valuable information on the rheology of the dough, as will be discussed later in this chapter.

The water absorption of a flour is influenced by four parameters:

- *Moisture content*; a flour with a moisture content of 13 % will have an apparent water absorption which is 1 % higher than the same flour at 14 %.
- *Protein content*; protein absorbs approximately its own weight in water, so that a higher-protein flour will naturally absorb more water than a lower protein one.

- *Starch damage level*; this is probably the major factor affecting the water absorption properties of flour, as discussed above. Excessive starch damage can cause a greying of the crumb colour and an opening of the crumb structure (Collins 1985).
- *Pentosan (hemicellulose) level*; these components are present, at levels of 2–3 % in white flours and up to 10 % in wholemeal (wholewheat). These non-starch polysaccharides have a very high water-binding capacity and, although present in the dough at very low levels, can actually account for absorbing up to one-third of the water in the dough (see Chap. 11).

The water absorption capacity of flours will typically vary from 50 to 54 % for biscuit flours up to 58–62 % for UK bread flours. The actual level of water added in a bread bakery may be somewhat higher than measured. This is because many recipe and process factors affect the consistency of the dough which can be tolerated in a plant. Water absorption data are useful for checking the consistency of the flour supply but should not be seen as an absolute measure of the water level to be used in the bakery.

Hagberg Falling Number

The Hagberg Falling Number (HFN) is a measure of the cereal *alpha*-amylase activity in the flour (Cauvain and Young 2009b). In the flour it has to be controlled by the choices made at the mill intake stage because it cannot be significantly affected by the milling process. It can be lowered by the addition of malt flours but no technique has been found to reduce the amylase activity and so increase the HFN. The prediction of HFN with flour blends cannot be based on a simple arithmetic mean and instead the values have to be converted to a liquefaction number using the following formula:

$$\text{Liquefaction number}\left(\text{LN}\right) = 6000/\left(\text{HFN} - 50\right)$$

Rearranging the equation we can convert back from liquefaction number:

$$\text{HFN} = 6000 + 50/\text{LN}$$

In the following example, two flours are blended 50:50; flour 1 has a HFN of 100 and flour 2 has a HFN of 300.

$$\text{Flour 1 LN} = 6000/\left(100 - 50\right) = 6000/50 = 120$$

$$\text{Flour 2 LN} = 6000/\left(300 - 50\right) = 6000/250 = 24$$

The liquefaction number of the blended flour will be:

$$\text{LN}\ \left(\text{blended flour}\right) = \left(120 \times 50\right)/100 + \left(24 \times 50\right)/100 = 60 + 12 = 72$$

Then HFN will be:

$$\mathrm{HFN} = \left(6000/72\right) + 72 = 83 + 50 = 133$$

The result is not the arithmetic mean of the two flours, which would have been 200 but is significantly biased towards the lower end.

The Rheological Properties of Wheat Flour Dough

For many breadmaking processes the rheological properties of flour are critical parameters in the flour specification. They are indicators of how a given dough will behave as it is being processed in the bakery, during proof and in the oven and the rheological characteristics are related to finished product quality. A variety of tests are used to measure the rheological properties of flour and all require a degree of interpretation by expert assessors in order to relate the measured data to the likely performance of a given flour in a given baking process (Cauvain and Young 2009a). Unfortunately, the complex nature of gluten with its combination of viscous and elastic properties make its characterisation in fundamental terms difficult. Thus, many of the rheology tests applied in the testing laboratory have a largely empirical bases; some mimicking the sensory assessment when bakers squeeze and stretch dough while others examine the dynamic changes which occur during mixing. It is important to recognize that there is no right or wrong way to assess flour rheology there are just different techniques which allow us to compare different flours. What matters most is the way in which the data are used.

Dynamic Measurement During Mixing

Under this heading are included the Brabender® Farinograph®, the Mixograph, the DoughLab and the Mixolab (Cauvain and Young 2009a). Each of these instruments yields a curve which is, in effect, a measure of the resistance of a mixture of flour and water to the movement of the mixer beaters as the rheological properties of the mixture change with the input of mechanical energy.

Using the Farinograph® as an example we can see that there are three pieces of information that can be deduced from a Farinogram (Fig. 12.3):

- *Dough development time (A)*; the time taken from the start of mixing to the point of maximum viscosity just before the curve starts to weaken. It will be longer with strong flours and shorter with biscuit flours.
- *Stability (B)*; measured from the point when the top of the graph first crosses the 500 or 600 line (or other fixed point), to the point where it drops below it, i.e. the

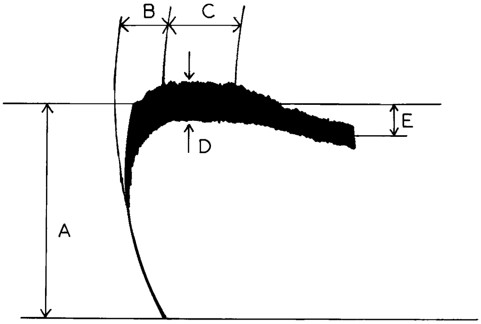


Fig. 12.3 Typical Farinogram. See text for key to symbols

time the curve is above the line. It gives a measure of the tolerance of the flour to mixing.

- *Degree of softening (C)*; the difference in height, measured in Brabender Units (BU), between the centre of the graph at the maximum viscosity, and the centre of the graph at a point 12 min later.

Some examples of the different farinograms obtained with different flours are given in Fig. 12.4. The dynamic rheology test is probably the most rapid of the three types of test being discussed under this heading; water absorption can be done in 10–15 min, the full curve probably taking another 10–15 min, depending on the flour. Because of these short testing times it is possible to use the Farinograph as a quality assurance tool.

The Perten DoughLab is equipment which can be used for the dynamic measurement of dough rheology during mixing. The mixing action is similar to that of the Farinorgaph®, as is the shape of the curve which is recorded (Bason et al. 2005). One adaption of the equipment allows for the fitting of a standard Farinograph® 50 g bowl to make the same dough rheology measurements, such as flour water absorption.

Stretching and Expansion Tests

Often in this type of test a flour–salt–water dough is prepared under standard conditions using a defined mixer. In one example, the Extensograph, the dough is prepared in the Farinograph mixer bowl. The salt is used at 2 % flour weight (2 g per 300 g flour) which remains the equivalent of typical levels in some breadmaking processes. However, as noted above (Chap. 3) salt levels are falling quickly in some parts of the world and such industrial changes begin to raise important questions as to the details of some current flour testing methods. In the current Extensograph test various attachments are then used to mould the dough to a standard shape before

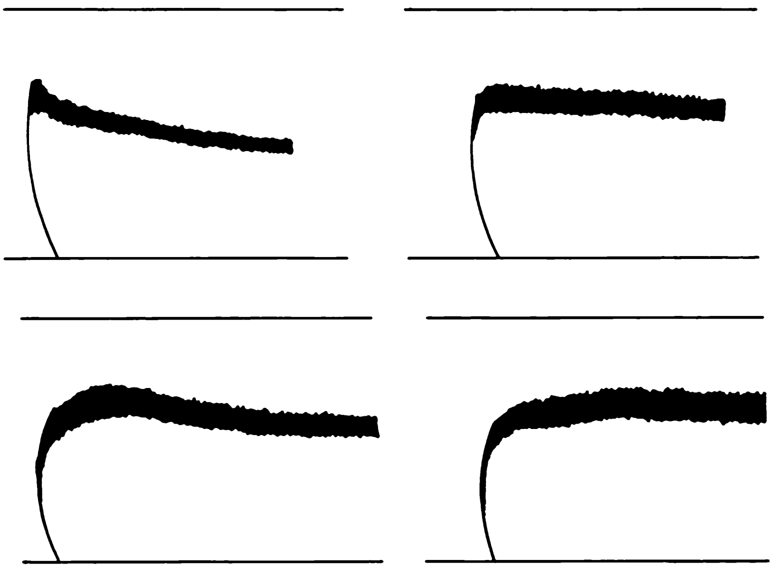


Fig. 12.4 Examples of Farinograms in which the flours become stronger, *left to right* and more elastic, *top to bottom* (based on data published by NABIM)

resting. After 45 min the dough is stretched, and the extensibility of the dough and its resistance to stretching are recorded. Immediately the doughs are re-moulded and allowed to stand for a further 45 min before being stretched once again. The dough pieces are once more re-moulded, and rested a further 45 min before the final stretch. This test is designed to give an indication of the baking performance of a dough over a time span of 135 min similar to that of a fermented dough. With modern short-time dough making methods the first stretch at 45 min is probably the most important one. With untreated bread flours the resistance will usually be around the middle of the graph (Fig. 12.5), but with weaker biscuit types, the curve will usually be well below the 200 BU line.

The Alveograph is commonly used to define the parameters for a good baguette-making flour. A dough is prepared using a set quantity of water and salt, and then extruded from the mixer and shaped following a standard method. After a resting period, the dough piece is clamped into a metal ring and inflated, while the pressure inside the bubble is measured against time and plotted on a graph (Fig. 12.6). The characteristics of the dough can then be assessed using the shape and area of the curve thus obtained. A modification of the Alveograph is the 'Consistograph', also supplied by Chopin. Both the Alveograph and the Consistograph provide information on the rheological properties of dough but the main difference between the two machines is that the latter is designed to test dough in which the water level is adjusted according to the water absorption capacity of the flour.

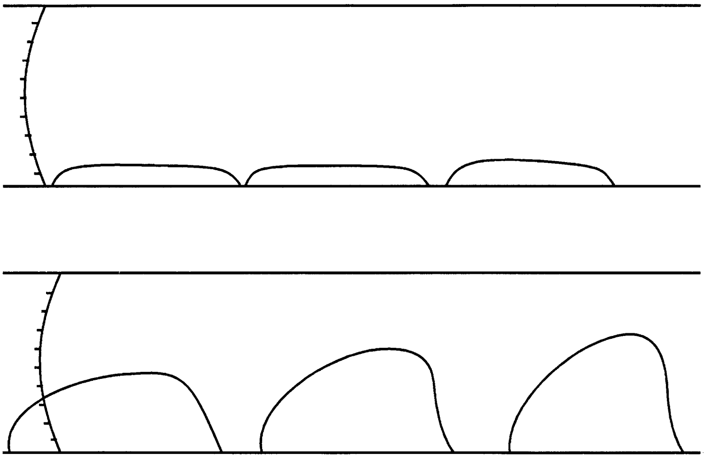
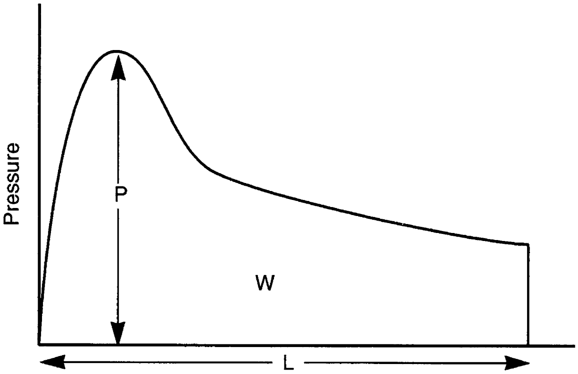


Fig. 12.5 Typical Extensographs for *top*, a biscuit and *bottom*, a bread flour, *left to right*, testing time 45, 90 and 135 min (based on data published by NABIM)

Fig. 12.6 Typical Alveograph (based on data published by NABIM)



Amylograph, Rapid Visco Analyser (RVA) and MixerLab

While much attention is rightly focused on the rheological properties of the gluten it may be appropriate on occasions to make measurements related to the starch of the flour. This assessment is most commonly made by heating a mixture of flour and water at a pre-defined rate until gelatinization has been achieved and in some cases beyond that stage. During heating changes in viscosity are recorded as the movement of the mixer blade is impeded by the flour-water mixture. Many variations of heating, holding and cooling may be applied to the mix according to the needs of the user. In the case of breadmaking evaluation of the starch properties in the flour are limited. Such instruments find use in the evaluation of rye flour (see Chap. 13) where they may be used to assess the level of enzymic activity (particularly amylase) and the degree of softening which may occur during gelatinization of the starch.

Choosing Appropriate Flour Testing Methods

In broad terms wheat flour testing methods fall into two categories; chemical and physical. Tests in the first category are commonly based on the analytical procedures which can be related to some fundamental chemical property of the flour while in most cases tests in the latter category are seldom related to fundamental measurements and are more closely aligned to the behaviour of the dough in the bakery (at least in the test bakery or the laboratory if not in the production bakery). Over the years tests in both categories have been and remain the subject of collaborative studies which enable the exchange of commonly understood data (Cauvain and Young 2009a).

However, care must be taken to recognise that the results which are obtained from such tests are only indicative of the performance of the flour in a given breadmaking environment. Most of the accepted methods have greatest value for wheat purchasing and assessing the consistency of the output from the flour mill. Therefore, care must be taken as to what tests and values might comprise a flour specification for use in a particular bakery (Cauvain and Young 2009b). In this context the methods used to assess the rheological properties of wheat flour doughs are the most difficult to use. The choice of method used in different parts of the world reflects to some degree, the choice of breadmaking process or regional or historical influences. As the methods vary in detail direct comparison of data between them is not possible to any great extent.

The use of rheological testing data as part of a flour specification can also present significant and sometimes unexpected problems. For example, the addition of flour treatment agents at the mill can be a means of adjusting the rheological properties of the flour within a given testing method to meet the specified values. This almost certainly means that the flour is consistent with respect to the specification but in many cases the baker will go on to add similar ingredients via an improver or as part of the bread recipe and this may lead to excessive additions of highly functional materials and in turn, unwanted consequences for dough handling and final bread quality. It is perfectly possible for bakers to be ‘over-dosing’ or compensating in the recipe or dough processing if that do not know what flour treatment additions are being made in the mill. The adjustment of flour rheology curves with ascorbic acid additions is one such example which should be kept in mind when choosing the appropriate testing methods as part of the flour specification.

Glossary of Milling Terms Used in This Chapter

Aspiration	A process using air to remove fine impurities from wheat
Break rolls	Fluted rolls designed to open up grains and release the endosperm
Conditioning	The process of bringing wheat to the appropriate moisture content for milling
Extraction rate	The amount of white flour extracted from the wheat, expressed as a percentage of the wheat entering the first break rolls
Flour dressing	Sieving of the various flour stocks
Grist	The blend of wheats to produce a given flour
Hectolitre weight	A measurement of wheat density, expressed kilograms per hectoliter
Low-grade	Flour of poor colour and poor functionality (in breadmaking terms)
Overtails	Name given to materials (stocks) which are too large to pass through a given sieve size
Reduction rolls	Smooth surfaced rolls designed to reduce the size of semolina particles to flour
Semolina	Coarse particles of endosperm
Screens	Sieve meshes of a given size
Screenings	Impurities removed from wheat as received at the mill
Screenroom	Part of the milling process designed to clean grain
Silo	A building for grain or flour storage
Stocks	Mill feeds to the different machines used in the mill
Straight run	Flour with approximately 76–78 % extraction rate obtained by blending individual machine flours
Throughs (thro's)	Name given to the stocks which pass through a given sieve
Patent flour	A flour produced from just top-quality mill streams with a very good colour (low ash content)

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Chapter 13
Other Cereals in Breadmaking

Introduction

The main thrust of the previous chapters has been accented towards the production of bread from 100 % wheat flours but, although such products are universal, there are some bread products around the world which are based on or include a high proportion of non-wheat cereals. In breadmaking terms, rye is the closest of the cereals to wheat with similar protein contents but a distinctly limited ability to form gluten. The closeness of wheat and rye has led to their crossing and the first 'artificial' cereal—triticale—which may also be used for breadmaking (Gustafson et al. 1991).

In the past, maize (corn), barley, oats, sorghum, millet and rice have all found their way into bread products at some time, usually when wheat and rye have been in short supply. More recently, in countries where these other cereals are commonly grown, they have been utilized in breadmaking to reduce the proportion of wheat flour being used if economic conditions necessitate the reduction of wheat imports or the need to use indigenous materials. In some cases it is possible to make a product which has some of the attributes of wheat breads with mixtures of some of these cereals by utilizing the gelatinization properties of their starches to form a bread-like, aerated structure. In these circumstances the lack of gas-holding capabilities of any proteins present in the flour must be compensated for by adding other bubble-stabilizing materials.

Rye Bread

Of all the non-wheat breads, those based on rye are the most common with production in central and Eastern Europe and North America. Rye is also grown as a feed wheat in Asia and South America. Although probably of Mediterranean origin (Lorenz 1991), cultivated rye (*Secale cereale*) is typically a plant of cool northern climates where it is better able to withstand the winter cold and grow farther north

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than any other cereal, hence its current favoured cultivation areas in northern Europe and North America. Rye is able to grow on a wider range of soil fertilities than wheat and is mostly sown in the autumn (fall) to over-winter.

Rye milling is a multi-stage process of similar complexity to that of wheat milling, with a number of break and reduction roll passages feeding sifters where the stocks are separated into various intermediate fractions and finished flours (Rozsa 1976). The numbers of rye flours and meals available and their classification varies according to the country of production. Key quality attributes are ash contents and colour, with low-ash rye flours being referred to as 'white' and high-ash flours as 'dark'.

The high levels of pentosans present in rye flours largely inhibit their ability to form gluten, and so in rye bread doughs the proteins play a lesser role in the structure-forming process. The quantities of pentosans and other soluble materials are particularly important in relation to breadmaking properties, and rye flours contain large quantities of matter which is twice as soluble in water compared with wheat flours.

The starch in rye gelatinizes at a relatively low temperature, 55–70 °C (130–160 °F), which coincides with the temperature range for maximum *alpha*-amylase activity. Rye has a low sprouting resistance and as a result particular attention is focused on enzymic activity in rye flour specifications, with measurement of Falling Number and Brabender® Amylograph® being common (Drews and Seibel 1976). The overall enzymic activity in rye flours is high compared with that of wheat flours, together with the potential for significant cellulase and proteinase activities being present. Evaluations of the potential of rye flour for making a particular type of bread are usually based on the interpretation of Brabender amylograms with flours having low viscosities being unsuitable for rye bread production, typically yielding low bread volume and problems such as splits under the top crust (Cauvain and Young 2009).

Breads based on or containing rye are most commonly seen in the northern, central and eastern Europe and the USA. The methods of manufacture and forms that the breads take differ noticeably between the main centres of production. The variety of rye breads is perhaps greatest in Germany (Fig. 13.1) where there are four main classes of bread, depending on the proportion of rye to wheat in the formula, which may use any of four raw materials to give a potential 16 bread combinations (Meuser et al. 1994). In the USA the range of rye breads tends to be less well defined and is generally fewer in number than in central Europe. Pumpernickel is a special rye bread produced on both sides of the Atlantic but in quite different forms.

In order to restrict amylolytic activity and breakdown of starch during baking, acidification of rye bread doughs has become common. Traditionally, lactic acid fermentation in a sour dough is preferred, although direct acidification can be achieved by the addition of acids such as citric or tartaric acid. Acidification of rye doughs improves their physical properties by making them more elastic and extensible and confers the acid flavour notes so characteristic of rye breads.

A preliminary heat treatment may be applied to some of the rye flour which will be used in the final mix. This process is commonly referred to as 'scalding' and is seen as a key element in the production of flavour in the final product (Petersen et al. 2005).

Fig. 13.1 German-style rye bread (Courtesy *BakeTran*)

Sour Dough Methods

The sour dough method begins with a ‘starter’ based on a pure sour culture prepared by inoculating sterile nutrient media with the appropriate bacteria. Initially in the pure culture, some dark rye flour and water are mixed to form a soft dough at 27 °C (80 °F) which is blended with salt, more rye flour and water to form the sour dough. Commonly the starter is used at the rate of 20 % of the final sour dough. Subsequent starters can take the form of a portion of the sour dough which has been stored at 5 °C (40 °F). The starter may be stored for a few days or even up to 6 months, though by this time the purity of the culture will have been lost and it is better to begin again with a new pure culture.

The activity of the sour dough needs to be controlled in order to inhibit the activity of unwanted microorganisms. This is usually achieved through the addition of about 2 % salt (based on flour weight). A fairly slack dough consistency is required for the sour dough; typically water absorptions will range from 80 to 100 % for rye meals and flours. The sour dough is formed at a temperature around 35 °C (95 °F) and allowed to cool to about 20 °C (68 °F) over a 24 h period. During this time the pH of the sour dough typically falls from around 5.8 to 3.5. The sour dough can be used for up to 9 days after preparation.

Dehydrated sours in dry powder form have become increasingly popular with bakers. Based on pre-gelatinized flours, organic acids or their salts and a dehydrated sour dough extract, they are more convenient to handle and ensure consistency of performance in doughmaking. Their rate of addition varies according to their source and individual preferences, but is typically about 2–6 % based on total flour weight.

Table 13.1 Example of rye wholemeal formulation

	Kg
Sour dough	80.0
Rye wholemeal	60.0
Salt	1.2[a]
Yeast	1.0
Water	25.0

[a] 0.8 kg salt contained in the sour dough

Doughmaking

The sour dough is blended with the other ingredients using a low or medium-speed mixer. The proportion of the sour to the other ingredients will vary according to the type of bread being made. A sample recipe for the production of rye wholemeal bread is given in Table 13.1. Intensive mixing is not normally required for rye doughs because they are not able to form gluten. Mixing times between 5 and 30 min are used depending on the type of mixer and its speed. Coarse rye wholemeals and whole rye grain doughs require longer mixing times.

Dryness and crumbliness in rye bread can be avoided by presoaking or scalding part of the rye wholemeal before doughmaking (Meissner 2013). Between 10 and 20 % of the meal is scaled with an equal weight of water 3 h before doughmaking and allowed to cool before adding it to the other ingredients. Water-binding substances are sometimes used as ‘improvers’ in rye bread, typically up to 3 % of pregelatinized potato, maize or rice starches, or a hydrocolloid or gum. A whole range of optional ingredients may be added to rye doughs for flavour or texture; they include buttermilk, soured milk, curd cheese, dried fruits and nuts.

Baking

Rye breads may be baked in pans, as oven-bottom (hearth) or even as batch breads. A traditional practice for oven-bottom rye breads is to prove the dough in a dusted basket, in the past made of wicker but now more likely plastic, which leaves a ‘ribbed’ appearance on the dough surface when the dough pieces are tipped out onto the oven sole for baking. Oven-bottom rye breads are often given a deep cut from the surface to about half-way down the dough piece. This improves heat transfer to the rather dense dough and prevents ragged breads along the side of the dough. Cutting also adds variety of form to the dough surface.

Baking conditions vary with bread variety and oven type. The lighter varieties can be baked under similar conditions of time and temperature to wheat breads, while darker and wholemeal forms may require up to 55 min for an 880 g loaf. A common procedure is to bake it first for about 20 min at 260 °C (500 °F) using a considerable amount of steam and then complete the baking at a lower temperature, typically 200 °C (390 °F).

Rye wholemeal bread can be baked using a form of steam-pressure cooking to avoid the formation of a normal crust. The dough pieces are held in tightly closed pans and put into an autoclave-type steam chamber for 5–8 h at 200 °C or 16–24 h at 100 °C (312 °F). The advantages claimed for this type of process include better nutritional value and moisture retention in the finished bread. This baking process causes a darkening of the crumb and the development of a bittersweet taste.

American Rye Breads

The four basic types of rye bread produced in the USA were first described by Weberpals (1950):

- Light rye bread made with a blend of wheat and rye flours, typically in the proportions 60:40.
- Heavy rye bread made with a sour dough process.
- Light, sweet, pan rye bread, a mixture of wheat and rye flours and made with a straight dough process.
- Light and dark pumpernickel made with a sour dough process. This product is quite unlike the original German pumpernickel and often contains fat and molasses in the USA.

Keeping Qualities of Rye Breads

The lower pH of rye breads, especially those made with sour doughs, inhibits microbial growth and confers a longer shelf life than that commonly seen with wheat bread products. The shelf life of rye bread may be further extended using a pasteurization or sterilization process. Such processing is usually carried out on the wrapped product so that the film used must be heat stable and have good barrier properties. The condensation developed within the wrapper is later reabsorbed into the product and has no adverse effect on product quality at the time of consumption. Some darkening of the products may occur but this has relatively little importance for rye breads, which tend to have naturally dark crumb colours. Conventional hot air ovens, steam chambers and microwave heating have all been used for the sterilization process. After treatment, the shelf life of rye bread may extend for up to 24 months.

Triticale

Interest in triticale stems in part from its nutritional properties, with higher protein levels and a more nutritionally acceptable amino acid composition than wheat (Gustafson et al. 1991). Intensive work to produce high-yielding varieties with improved product performance has taken place in Poland (Achremowicz 1993) and elsewhere for about 40 years, but has not increased its wider acceptance as a human foodstuff and most triticale production goes to animal feed.

Triticale grains are milled in a similar manner to wheat and rye and can yield straight run flours with relatively low ash contents. Wheat milling techniques tend to give higher extraction rates and are therefore preferred. Early strains of triticale gave flours with poor baking performance, in part because of higher *alpha*-amylase activity and lower paste viscosity than wheat flours (Lorenz 1972) and in part because of weaker protein qualities, although a wide variation in the rheological properties in triticale flours has been noted (Macri et al. 1986). Later developments of triticale varieties and the use of bread improvers, such as SSL (Tsen et al. 1973), have brought the baking performance closer to that of wheat flours, although the 'quality gap' is still significant.

Achremowicz (1993) found that triticale bread baked with a three-stage method using a rye pre-ferment gave a loaf which rose well with the required shape, had an elastic crumb and pleasing odour and flavour. The bread remained fresh for a long period. The basic elements of the breadmaking process he used were:

- A pre-ferment based on rye flour at 10 % total flour fermented for 24 h at 28 °C (82 °F);
- A sour with 50 % of the total triticale flour, 1–2 % yeast and water to a total of 200 %, fermented for 3 h at 32 °C (90 °F);
- A dough based on the sour, the balance of flour as triticale, 1.5 % salt and water to a dough yield of about 160 %, fermented for 30 min at 32 °C;
- Unit pieces were proved for 25–45 min at 32 °C;
- Baking at about 240 °C (464 °F).

In summary, we can see that triticale has some potential in breadmaking, although the performance of triticale flours is closer to that of rye rather than that of wheat. In areas where wheat cannot be grown successfully because the land or farming practices have marginal agricultural potential, triticale offers a viable alternative to wheat and greater potential than rye. Acceptable bread quality is achieved using rye bread manufacturing techniques rather than those used for wheat breads. However, given the improvements which it has undergone since its introduction, triticale has been successfully transformed from 'scientific curiosity to a viable crop' (Varughese et al. 1996).

Oats

There is increasing interest in the use of oats in conjunction with wheat flour for breadmaking because of the health benefits associated with their introduction. In particular oat flours have much higher levels of β-glucans which are associated with the potential for lowering blood cholesterol levels. Oat flours are not capable of forming a gluten network strong enough to retain large quantities of gas and so bread products are usually based on a high proportion of wheat flour in the recipe. Oats also have a high lipid content for a cereal and so are prone to rancidity (McMullen 1991) and long-term storage requires inactivation of enzymic activity to

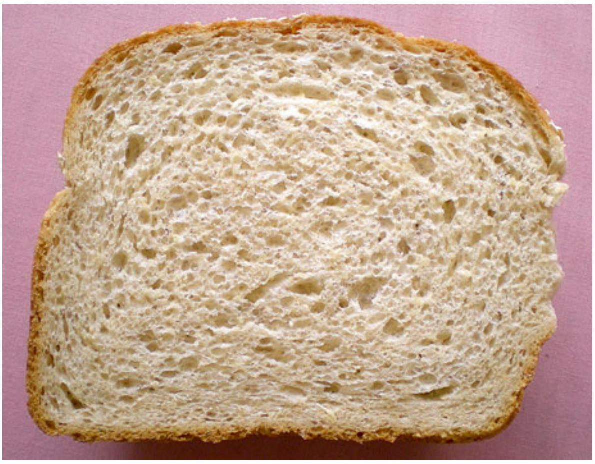

Fig. 13.2 Structure of pan bread containing oats (Courtesy *BakeTran*)

reduce the likelihood of rancidity. The first stage of milling oats aims to separate the hulls from the grains, the later commonly being referred to as groats. After separation stone or impact milling is used to yield a range of finished products, including bran, flour, flakes and cut groats (Welch and McConnell 2001). The high oil level and lipase levels in the groats necessitate the application of heat—kilning—to inactivate the enzymes and yield a product with a reasonable rancidity-free shelf-life.

When added to wheat flour doughs, oat flours reduce the ability of the system to hold gas and the final loaf has a bland taste and firm texture. For these reasons oats have only become an established ingredient in bread products (Fig. 13.2) when its nutritional contribution can override its adverse effects on bread quality or where its unique flavour can provide positive benefits. An example of the latter is the use of oats in the manufacture of UK sandwich breads which have to be held at 5 °C prior to sale. In some cases the sandwiches may be eaten when they are still at refrigerated temperatures and at such temperatures white bread often appears to lack flavour. In these circumstances the addition of oats to white flour for the manufacture of sandwich bread helps to restore flavour in the final product.

Barley

Barley grains were a common component in breads of the past with the addition of barley being used to being used to limit the amount of wheat being consumed while still providing some nutrition. Gradually as wheat became more plentiful and cheaper it was possible for most people to afford wheat bread and barley grains stopped being a common bread component (Kent and Evers 1994). There are higher levels of β-glucans in barley than wheat though significantly lower than those in oats. Never the less the use of barley is attracting interest and as with oats as a 'nutritional supplement to wheat flour' (Fig. 13.3).

Fig. 13.3 Bread containing barley and (Courtesy *BakeTran*)

Barley grains have a similar morphology to wheat but are differentiated by having a strongly attached husk which must be removed before malting or milling can take place. Most barley types are characterised by being hulled though some varieties of naked (i.e. hull-less) barleys are available. If a hulled barley is used it is common to pearl the grains before milling, this action removes part of the hull by attrition and tends to yield rounded grains. Blocking (shelling or de-hulling) may also be used to remove part of the hull. Pearled, blocked or naked barley grains are commonly tempered and turned into flour using a combination of roller mills and sifting arrangements similar to that employed for wheat (see Chap. 12). The final product of the process can be a wholemeal-type flour which can be used for baking.

Perhaps the most common use of barley in the brewing industry. The malting of barley grains produces distinctive flavours which are carried through to the final product, and because of this the grain has found some use in the baking industry. After the various stages of the malting process, a milled barley malt may be produced for use in breadmaking. This powdered form will have a high diastatic (enzymic) activity which can be used to supplement breadmaking flours. The enzymic activity is usually dominated by (cereal) *alpha*-amylase and proteolytic enzymes. The former can be beneficial in improving the gas retention abilities of flours, although such enzyme-active malt flours should be used with caution in breads which are later to be sliced, because of the high levels of dextrins which will be produced during dough processing and baking (Chap. 3). The proteolytic activity can also have both beneficial and adverse effects since they cause softening of the

Fig. 13.4 UK malt breads (with permission Edme)

dough. Some softening can improve dough machinability, but too much may cause dough to stick to equipment surfaces during moulding and intermediate proof.

In addition to using malt flours it is possible to use malt extracts and syrups. These too will have some enzymic activity but are more likely to be used by bakers for their contribution to flavour. They find use in some special ‘malt’ breads seen in some parts of the world, especially the UK (Fig. 13.4). In such cases the sticky crumb resulting from the high enzyme activity is seen as a positive attribute. Gas retention in these specialist doughs can be so great and the crumb density at the centre so low that the loaves will collapse during conventional cooling. They therefore require the use of vacuum cooling (see Chap. 5) to preserve the integrity of their structures.

Other Grains and Seeds in Bread

The never-ending quest by marketing departments for new products to tempt consumers, and for ingenuity in product developers, has led to the development of many ‘new’ breads with special characters, such as the seeded variant of a square bread product illustrated in Fig. 13.5. Sold already split such products represent an alternative to the more traditional bread roll or sliced pan loaf for sandwich making. In some cases the addition of grains are made in order to deliver specific nutritional properties or textural characteristics. Levels of addition of non-wheat grains are usually quite modest and are made to a suitably strengthened wheat flour-based dough. Since the latter has to carry materials which are unlikely to contribute positively to

Fig. 13.5 Split, square, seeded bread product for sandwich making (Courtesy *BakeTran*)

the gas retention or dough rheology in the system, special attention must be focused on the qualities of the base wheat flour, improvers and the breadmaking process which is to be used. A wide range of grains and seeds might be added to wheat flour doughs and so only a limited number of examples have been chosen to highlight some of the technical issues which may arise in bread production.

In multi-grain breads it is usual to add a portion of whole, cracked or kibbled grains to the wheat flour base. Ready-prepared premixes are available from millers and other suppliers which may include improvers, flavouring and colouring agents. While cleaned grains can be added directly to the wheat flour dough, some problems can arise from this procedure. Like wheat, other grains are subjected to microbial contamination during growth and harvesting and this can be carried through to the final product. Of particular concern is the presence of the rope-forming bacteria *Bacillus subtilis* (Chap. 10) with its potential for causing product spoilage after baking. Thorough cleaning of the grain and some form of heat or surface treatment may be helpful in reducing the levels of microorganisms.

The other main problem with adding large particles of grain directly to bread dough is related to their hardness, which will be considerably greater than that of the surrounding bread crumb. This will certainly provide a contrast in textures but may also result in a rapid trip to the dentist! To obviate this problem, whole grains are often given a short period of soaking to reduce their hardness, a technique often used in treating grains for animal feed (Kent and Evers 1994). Steam rolling and steam flaking may also be used, depending on the particular form of the grain required. Raising the moisture content of the grains is not without risk since the higher water levels will provide the potential for extra microbial growth.

Modifying Nutritional Properties with Non-wheat Sources

Bread, especially wholemeal (wholewheat), is a naturally rich source of dietary fibre. The fibre largely derives from the bran skins of the wheat berry. There have been some product developments which have sought to raise the level of dietary fibre in breads by using fibre sources other than those occurring in wheat. In some cases the drive behind such developments has been to increase the nutritional value of white bread while retaining appeal to some sectors of consumers (Hartikainen and Katina 2012). While wholemeal and similar high-bran breads have the required nutrition, their appeal appears to be limited with younger consumers who seem to prefer the textural and flavour characteristics of white bread. The introduction of white-coloured fibre sources, such as pea and other fibres, enabled the development of bread products which met the requirements of both younger consumer groups and nutritionists. As with bran in wholemeal flour, non-wheat fibres generally play a negative role in promoting gas retention in the dough or in improving its rheological character, so that formulations must take into account the dilution effect of the fibre on the functionality of the system.

Protein supplementation of wheat breads is also a subject that has attracted attention. In part the interest is to try and deliver a more ‘rounded’ nutritional profile using a wide range of non-wheat sources of protein (Rosell 2012). Potentially nutritional improvements to wheat based baked products may be delivered by changing the choice of wheat or by improving agronomic practice the addition of supplements either to the flour at the mill or in the bakery remain the most likely way forward.

Gluten-Free Breads

An essential feature in delivering the qualities which commonly characterise bread is the development of a network of hydrated protein (gluten) in the dough which is capable of retaining the carbon dioxide gas generated by yeast fermentation. However, it is considered that around 1–2 % of consumers may suffer from a medical condition commonly referred to as coeliac disease which is a digestive disorder arising from allergic responses related to the gluten forming proteins present in wheat and some other grains (Wieser et al. 2012). This condition has been recognised for some time and in response many bakers have developed gluten-free breads and other baked products (that is without the presence of the gluten forming proteins which are responsible for the allergic reaction). The manufacture of such gluten-free products is a specialist activity and should not be undertaken by bakers without segregated production facilities and stringent cleaning regimes designed to prevent accidental contamination of gluten-free product and the equipment used in their manufacture. Because gluten-free bread production is a specialised topic readers are referred elsewhere for a more detailed discussion of the issue and approaches to be used (Arendt and Dal Bello 2008). The volume of gluten-free bakery products being manufactured continues to increase at the time of writing (Anon 2013).

In the case of gluten-free breads the 'dough' which is formed is often closer to the viscosity of a cake batter than a standard bread dough, and because of this similarity many of the techniques used to stabilize gas bubbles during processing and baking are commonly used in cake production. Cakes are produced by forming a complex emulsion and foam system—the batter—which is processed by being heat set. When eggs and sugar are whisked together during the mixing of the batter, large numbers of minute air bubbles are trapped in the batter by the surface-active proteins of the egg white and the lipoproteins, which form a protective film around the gas bubbles and prevents them coalescing. Other surface-active materials, such as distilled monoglycerides, may be used to augment the effect of the egg proteins (Cauvain and Cyster 1996). This is especially true if oil or fat is added to the batter. If the level of added fat is increased sufficiently, the solid fat can take on the role of stabilizing the air bubbles. In this latter case the fat crystals align themselves around the air bubbles, thereby trapping and stabilizing them. This is possible because the oil fraction of the fat allows the crystals to move and at the same time stick to each other like links in a chain. The ratio of liquid to crystalline fat, and the size of the individual crystals, are very important in controlling cake quality (compare with the effects of solid fat in the CBP; Chap. 3).

As the temperature of the batter rises in the oven, the trapped gas bubbles expand and eventually, just as the mass of batter is setting, they burst into one another to form the porous structure of cake crumb. In the case of cake batters, carbon dioxide gas will be generated by the added baking powder and will add to the inflation of the initial air bubbles. The similarities between bubble creation in cake batters and bread doughs are clear even if the mechanisms by which they are stabilized are quite different. There is no significant gluten formation in cake batters, in part due to the higher water levels, the presence of higher fat levels and the presence of sugar. During the early stages of heating in the oven, the viscosity of the batter slows down the movement of the gases in the system so that the batter expands. In the absence of gluten formation a significant contribution to the final product structure comes from the gelatinization of the starch in the flour and it is that property which must be exploited when making wheatless breads.

More recent developments with gluten-free breads are based on products manufactured with a more dough-like and less batter-like character. While more dough like, the unbaked matrix does not have sufficient cohesion to be moulded like a gluten-containing dough. Stickiness can be a particular problem with gluten-free doughs and so often the practice is to deposit directly into the pan without moulding which makes it difficult to achieve a uniform external shape, especially the top crust. After depositing the gluten-free dough (batter) will be proved, baked and cooled in a similar manner to standard bread products. The final loaf may also be sliced.

The structure of gluten-free breads relies heavily on the gelatinization character of the mixture of starches which are used in the recipe. Since many of the starch granules from the different sources will be intact at the beginning of the manufacturing process, their water absorption capabilities are limited and so gluten-free formulations commonly contain a gum or modified starch to help absorb water until the gelatinization processes begin. A mixture of starch sources is used in order to extend the temperature range over which gelatinization occurs; in a way which is comparable to the wheat starch gelatinization—protein coagulation processes in standard bread (typically covering 60–75 °C, with pre-swelling of starch in the region 40–60 °C).

Without a network of protein, gluten-free breads tend to become dry and crumbly during storage. This process is exacerbated by the changes in starch character during staling. Anti-staling strategies and starch complexing agents are commonly added to formulations to improve the overall acceptability of gluten-free products. More recent developments have been associated with the use of sour dough (Brandt 2012). As noted above, since bread products do not contain the high levels of fat and sugar that occur in cakes, we have to seek alternative means for trapping and stabilizing gas bubbles in gluten-free bread dough. Gums, stabilizers and pre-gelatinized starch can all be used to provide part or all of the gas occlusion and stabilizing mechanisms we require. Non-gluten forming colloidal proteins may also have a role in gluten-free bread manufacture (van Riemsdijk and van der Goot 2011).

Yeast can be used as the alternative source of carbon dioxide in the dough rather than baking powder, or they can be used together. The yeast will provide gas for bubble expansion in proof provided that sufficient substrate is available for fermentation to proceed. If insufficient substrate is available, then small additions of sugar may be needed to assist the yeast. Low levels of salt should be added for flavour.

Mixing methods for gluten-free bread dough can vary from the basic hand mixing, to mechanical, planetary-style and even high-speed, continuous batter-type mixers. Dividing of the bulk dough from the mixer may be with common bread dividers (see Chap. 4) or with batter-type depositors. If a dough is being made then shaping is perhaps the most difficult part of the manufacturing process for gluten-free breads, in part because of the stickiness referred to above, which commonly restricts the ability of the baker to deliver a totally uniform moulded shape to the pan. Proving and baking are carried out in a similar manner to that of standard bread production.

Bread Without Wheat

While rye and triticale breads may fall within the category of 'wheatless' breads, this section heading is intended to cover those cereal products which are not normally considered for the production of bread because they lack proteins capable of forming gluten in even the smallest quantities. Neither is it proposed to discuss the use of such cereals in 'composite' flours where they have been blended with wheat to reduce the wheat component, or where dried gluten has been added. Such practices are common in countries wishing to make a bread product but also wishing to reduce the importation of wheat. For the cereals which will be discussed under this heading the main structure-forming component in the flour will be based on the indigenous cereal starch, supplemented on occasions with other stabilizers to ensure stability of the gas bubbles in the 'dough'. Yeast and the generation of carbon dioxide gas by fermentation will be essential ingredients in the formulations and processing methods considered.

Examples of Wheatless Breads

There are many potential recipes for wheatless breads and the following are a few examples by way of illustrating the potential for such developments.

Cassava Bread (Satin 1988)

	% Flour weight
Cassava flour	100
Sugar	4.9
Egg white powder	2.3
Salt	2.3
Oil	5.7
Yeast	5.7
Water	120

- Take 15 parts of the flour and boil with the water for 4 min.
- Replace evaporated water, add the remaining ingredients and mix for 10 min.
- If dried yeast is used rehydrate with a little sugar and water before use (note that some powdered yeast do not require re-hydration).
- Scale into a pan, leave to prove and bake.

Rice or Maize Bread (Satin 1989)

	% Flour weight
Rice or maize starch	100
Sugar	4.4
Salt	1.7
Oil	1.7
Yeast (fresh)	1.0
Water	140

- Take 17 parts of the starch and boil with 92 parts water until translucent.
- Add the remaining ingredients and mix for 5 min.
- Scale into a pan, leave to prove and bake.

Sorghum Breads

Sorghum (*sorghum bicolor*) is widely grown in areas of low rainfall and poor soil conditions and is cultivated throughout central and southern Africa, central Asia and the Indian sub-continent. It has many food uses (Dendy 2001) and there has been some interest in its use for making ‘bread-like’ products (Taylor et al. 2005) as

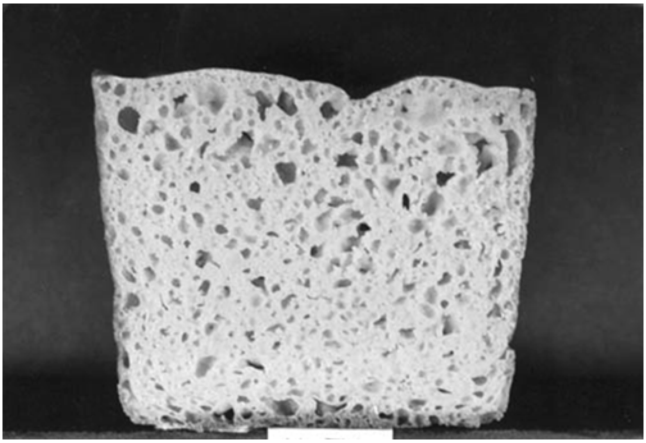

Fig. 13.6 Sorghum pan bread

an alternative to the importation of wheat. There has also been interest in sorghum as a component of gluten-free products (Arendt et al. 2005).

An example of a sorghum-based bread product is illustrated in Fig. 13.6 and is based on the following recipe:

	% Flour weight
Sorghum flour	100
Yeast (compressed)	4.2
Salt	2.1
Skimmed milk powder	12.0
Sodium carboxy methyl cellulose	1.0
Water	100
Baking powder	2.0
Soya flour	2.0

- Mix the ingredients for 6 min using a planetary mixer.
- Scale 460 g (1 lb) into rectangular bread pans.
- Prove until the dough reaches the top of the pan, then bake.

Sorghum and Maize Bread Using a Continuous Mixer (Fig. 13.7)

	% Flour weight
Sorghum flour	50
Maize starch	50
Yeast (compressed)	8.3
Salt	2.1
Skimmed milk powder	12.0
Sodium carboxy methyl cellulose	1.0
Dried egg albumen	15
Water	80

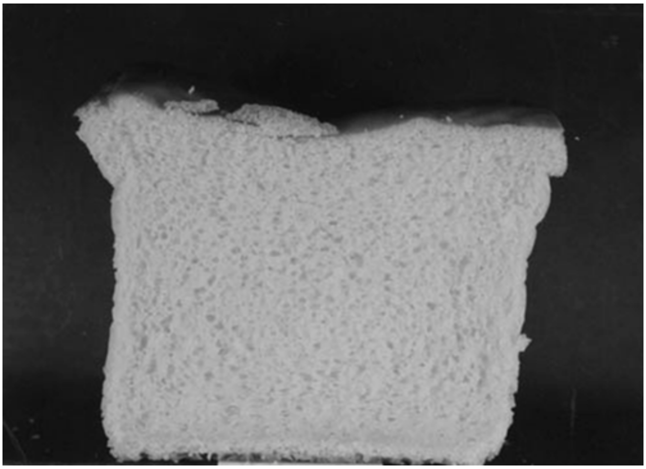

Fig. 13.7 Sorghum and maize bread manufactured using a continuous batter mixer

- Blend the ingredients on a planetary mixer and then pass through a continuous cake batter-type mixer.
- Scale, prove and bake.

Sorghum Flat Breads (Fig. 13.8)

	% Flour weight
Sorghum flour	50
Maize starch	50
Yeast (compressed)	2.1
Salt	1.8
Fat	0.7
Improver	1.0
Water	80

- Mix for 5 min.
- Sheet to about 15 mm (0.5 in) thick and cut out suitable shapes.
- Bake on flat sheet or hotplate for approximately 15 min.

The success, or otherwise, of wheatless bread production, as with any other bread type, lies in being able to obtain consistently a raw material of known characteristics. It is unfortunate that in many cases the attributes required from the flour, meal or starch are, as yet, not fully appreciated, so that baking results and final bread quality may be somewhat variable. Nevertheless sufficient work has been done to show the considerable potential for wheatless breads and the opportunities this can provide for bread production in countries which have little wheat available.

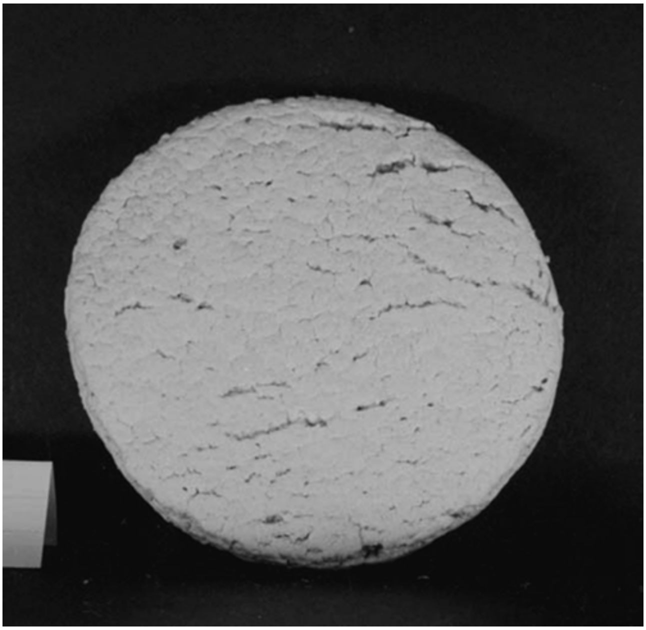

Fig. 13.8 Sorghum flat bread

Unleavened Breads

Many of the unleavened breads seen in different parts of the world are based on wheat flour, although seldom in the same form as we would see for the production of ‘Western-style’ breads since they are not always based on ‘white’ flour. In many cases the wheat flours used can be described as ‘high extraction’, brown and occasionally wholemeal and so can be considered under the general heading of this chapter.

The most usual form of unleavened breads is flat. They seldom contain yeast, though they may make use of sour and mother doughs and in some cases sodium bicarbonate. In addition to their flatness, many of the unleavened breads have a characteristic split or ‘pocket’ created during baking and which remains in the cooled product. This distinctive feature can be used to hold a filling because the bread will ‘puff-up’ when reheated.

There are a wide range of flat breads made around the world and some of these are given in Table 13.1. In Egypt the term ‘balady’ probably covers around 30 variations (Evans 1983). To illustrate the range of flat breads a few examples are given below, but bear in mind that with traditional products such as these, recipes will vary widely (everyone has their own favourite!).

Recipes for Unleavened Breads

Balady

	% Flour weight
Starter	
Old dough	11
Flour	100
Water	50
Dough	
Flour	100
Water	75.0
Salt	0.6
Starter	10.0

- Use a flour of about 85 % extraction (or a blend of 75 % white and 25 % wholemeal).
- Mix for about 20 min to produce a soft dough.
- Scale at 180 g (6 oz), mould round.
- After 15 min intermediate proof, flatten.
- Prove for 1 h and bake.

Chapattis

	% Flour weight
Flour	100
Water	70
Salt	Optional
Oil	Optional

- Use a flour with about 85 % extraction.
- Mix to form a soft dough, rest for 30 min.
- Scale around 50 g (2 oz), mould round.
- After a short rest roll out to about 2 mm (0.1 in) and bake with one or two turns.

Naan

	% Flour weight
White flour	100
Yeast	3.8
Salt	0.6
Baking powder	1.3
Caster sugar	2.5
Egg	15.0
Oil	7.5
Natural yoghurt	15.0
Milk	43.8

- Mix to a dough and ferment for 1 h.
- Scale at 110 g (4 oz) and mould to an oval shape.
- Bake (traditionally on the sides of a Tandoor oven).

Flours for Unleavened Breads

Although unleavened and flat breads are products which are not expected to achieve and maintain high specific volumes (low densities), they do demand quite specific characteristics from many of the flours used in their production, especially wheat flours. The difficulty for the miller supplying smaller bakers of flat breads is that the product requirements are subject to significant local variation and flour properties are often ill-defined. With the move towards larger industrial scale baking the specification of flours for flat bread production are becoming more concise. There are two critical areas in the production of unleavened breads where wheat flour characteristics play major roles; one is in the doughmaking stage and the other is during baking. In dough preparation the quality of the protein in the wheat flour will significantly affect the way in which the dough piece deforms under sheeting. High resistance to deformation and significant elasticity will result in the dough pieces tearing when thinly sheeted, and loss of shape after forming as elastic regain in the dough takes effect. The flour must be capable of producing a dough with good extensibility, so that tearing during sheeting is minimized and that the dough is capable of considerable and rapid expansion during the short baking cycle. Treatment of wheat flours is not normally required for these products since most treatments tend to make the dough less extensible. Protein content is probably of lesser importance than protein quality.

Conclusions

Although the majority of bread products are based on wheat, it is possible to use other cereals in bread production. In many cases the other cereals are seen as ‘additions’ to make wheat breads ‘more interesting’ (e.g. multi-grain breads), although many cereals are capable of making products with special characters of their own, e.g. rye bread.

In many parts of the world unleavened or flat breads have evolved with the passage of time and they too have become products in their own right with specific characters and raw material requirements.

In many countries the growing of wheat presents some difficulties with our present skills and technology. In these countries the concept of bread is well known, having been carried there with trading and social links, but the purchase of wheat itself presents other challenges for the populations concerned. In such cases, alternative and locally available cereals may be used to make breads with many of the attributes of those made with wheat.

Breadmaking has always provided diversity of form, shape and flavour, even when the products have been based exclusively on wheat, but as we improve our understanding of the properties of our available raw materials the opportunities for adding other cereals increase dramatically. Customers are always seeking novel products and new taste sensations, and with the wide range of cereals available for breadmaking there are many more new products waiting to be developed.

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