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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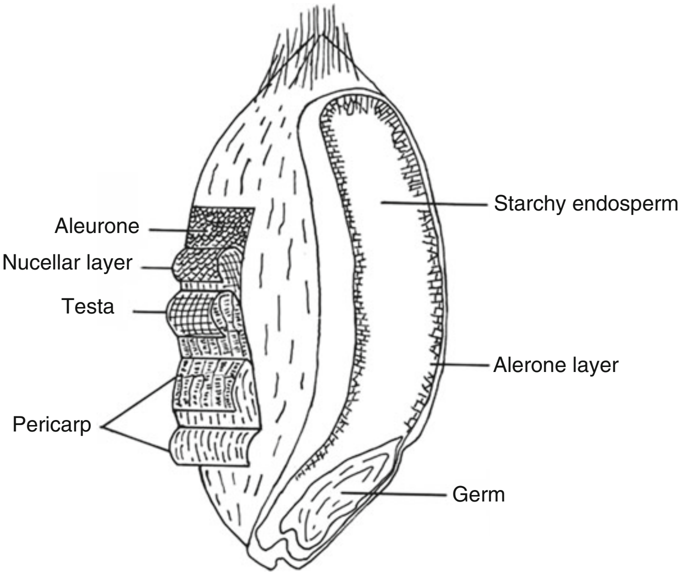


Fig. 12.1 The wheat grain (not to scale)

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 $\times$ 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

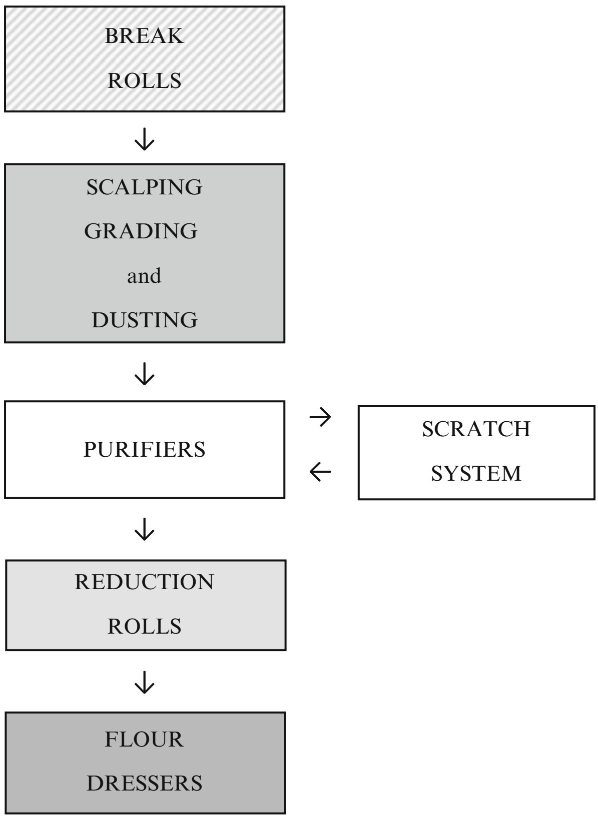


Fig. 12.2 Schematic of a flour milling process

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:

$$\text{HFN} = (6000/72) + 72 = 83 + 50 = 133$$

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

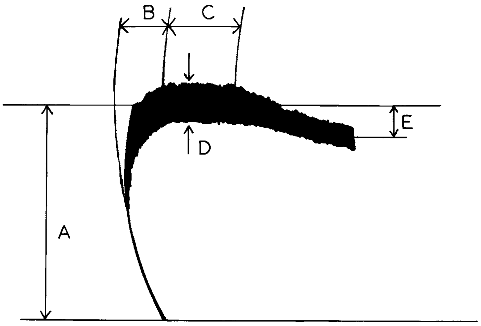


Fig. 12.3 Typical Farinogram. See text for key to symbols

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

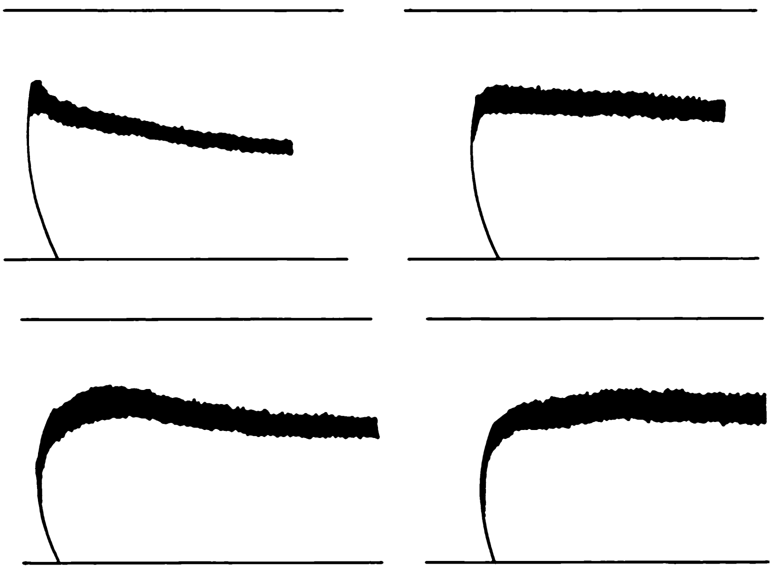


Fig. 12.4 Examples of Farinograms in which the flours become stronger, *left to right* and more elastic, *top to bottom* (based on data published by NABIM)

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.

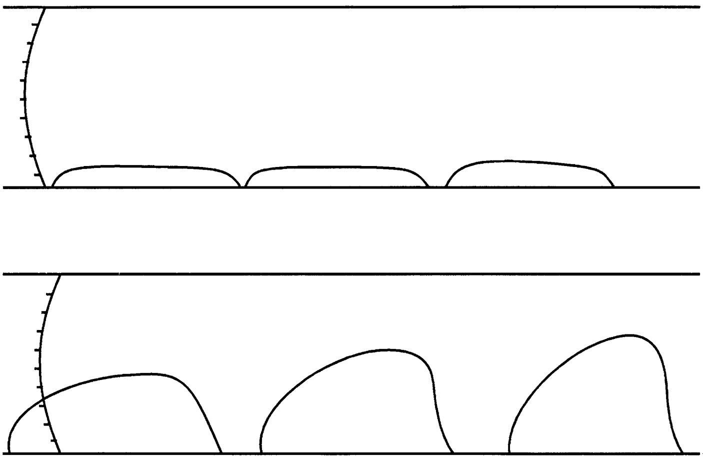
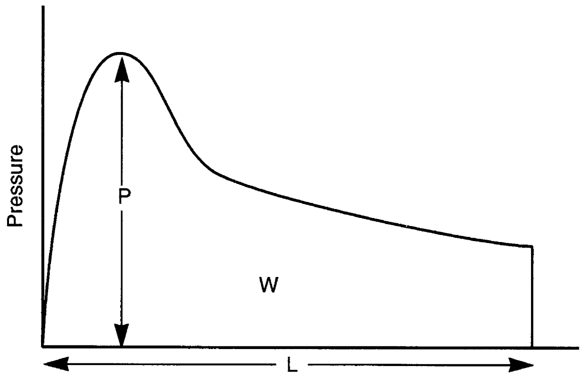


Fig. 12.5 Typical Extensographs for *top*, a biscuit and *bottom*, a bread flour, *left to right*, testing time 45, 90 and 135 min (based on data published by NABIM)

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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