Other Traditional Durum-Derived Products

Joël Abecassis
Bernard Cuq
Institut National de la Recherche Agronomique
UMR Ingenierie des Agropolymeres et Technologies Emergentes
Montpellier, Cedex, France

Gaetano Boggini
Department of Crop Production
Faculty of Agriculture
University of Milan
Milan, Italy

Hacène Namoune
Institute of Nutrition and Food Technology
University Mentouri of Constantine
Constantine, Algeria

OVERVIEW

Durum wheat, *Triticum turgidum* subsp., *durum* Desf. (also known as *T. durum*) is distinguished from common wheat, *T. aestivum*, by its genetic, morphological, and physiological traits. The grain shape is more elongated; its endosperm has an amber color; and its texture is glassy and very hard to crush. In terms of chemical composition, durum wheat is generally characterized by its high amounts of protein and of carotenoid pigments.

The glassy texture of its endosperm gives durum kernels the ability to be processed into original cereal products of whole or crushed grains. The semolina obtained after milling offers the agglomeration properties needed for couscous production. Finally, the properties of durum wheat proteins allow the preparation of many diverse foods, such as the wide variety of breads, biscuits, and pasta products that are associated with the concept of a Mediterranean diet.

Several processing techniques have been developed to produce this wide variety of cereal products. The implementation of these processes was probably largely dependent on energy availability but also on the ability to use these products around the Mediterranean basin.

The purpose of this chapter is to describe some of the widely diverse products—except pasta products (see Chapter 9)—and processes derived from durum wheat by considering products resulting from three levels of increasing energy use: those consumed in the form of grain, those made from the agglomeration of semolina, and those made from semolina and processing flour by baking.

DURUM WHEAT PRODUCTS FROM GRAINS

The very hard texture of durum wheat kernels allows them to be used following both a conventional milling process or a dehulling process similar to rice-kernel whitening. Developed in the Western countries, the milling process (see Chapter 8) is used nowadays all over the world to produce semolina as the raw material for several end products (especially pasta and couscous). Nevertheless, dehulling is still widely used in traditional areas of durum wheat production (the Middle East and North Africa). Moreover, the food trade, the migration of populations, and technical innovation have resulted in the consumption of durum wheat products in form of grain in Western countries also. The most important issue for the use of grain products is the time necessary to cook them (about 1 h). The aim of the associated processing steps is to achieve a drastic reduction in the cooking time of grain products. This chapter presents some of these products and their relative processes.

Bulgur

Bulgur is a cracked, precooked wheat grain. After cleaning, the grain is first cooked to gelatinize the starch. Then it is dried, partially dehulled, and ground into coarse fractions to reduce the rehydratation time to about 15 min.

Bulgur can be prepared from several types of grain (Koksel et al 1999), but durum wheat, with a high thousand-kernel weight, a vitreous endosperm, and high gluten content, is preferred (Ozboy and Koksel 2002). Grain processing starts with cleaning—washing the grains to remove stones and light impurities. The following step is a cooking operation. Traditionally, grains are boiled in water in large cauldrons. During cooking, grain size increases and water is absorbed to obtain uniform gelatinization of starch. Precooking is critical in controlling the yield of pearled grain as well as the sensorial properties of the end products (stickiness). Complete gelatinization of starch must be obtained. Generally speaking, these conditions are achieved by cooking the grain in heated water for about 45–60 min. The optimum cooking time was determined with different methods by Bayram (2005) as 40 min, resulting in 100% gelatinization without any deformation of the wheat kernel. Within the grain, starch gelatinization follows a first-order reaction kinetics. The reaction rate constant (K_r) value was measured as about 10^{-5}–10^{-4}/s by Turhan and Gunasekaran (2002). The rate of the gelatinization reaction increased with increasing temperature, and the effect of temperature on K_r was evaluated using an Arrhenius-type reaction. Turhan and Gunasekaran (2002) determined the average activation energy (E_a) to be 137 kJ/mol below 75°C and 79 kJ/mol above 70°C, assuming that the starch gelatinization is effectively controlled by water transfer below 75°C and the reaction of starch with water above 75°C. According to Sing et al (2007), pressure cooking (15 psi for 15 min) after soaking the grain at 60°C for 3 h is the most efficient hydrothermal treatment. This precooking treatment yielded higher pearled grains with higher hardness.

After cooking, the product undergoes a drying step, which is traditionally accomplished by spreading the grain under the sun. Hayta (2002) compared several drying methods for their effects on bulgur characteristics. The brightness (*L*) value of pilaf bulgur was found to be significantly higher for solar-dried, sun-dried, and microwave-dried samples compared with tray-dried bulgur samples. The redness (*a*) and yellowness (*b*) values of bulgur were also affected by the drying method as well as some other characteristics (water and oil absorption), whereas flavor and mouthfeel were not.

The drying process was followed with nuclear magnetic resonance by Turhan et al (2001). Fick's diffusion law seems not to be applicable to describe the moisture transfer during drying of the gelatinized wheat grains. The drying took place in the falling-rate period, which was approximated by two regions: the first and second falling-rate periods (FFRP and SFRP, respectively). The internal drying coefficient linearly increased with increasing drying temperature and was almost an order of magnitude higher (10^4 vs. 10^5/s) during FFRP than SFRP.

The dried grains are then tempered with moisture to allow dehulling by peeling (friction) in order to partly remove the outer layers and are spread out again for a final drying. After this stage, the grains are cracked into coarse particles and sized to obtain the final product. All these operations are traditionally done by hand but are now operated on an artisanal/industrial scale. Grinding is a crucial step, as it determines either the cooking time or the yield of the end product. Bulgur milling must deliver translucent particles with ovoid shape and uniform size (>0.50 mm). Several devices (roller, double-disc, and vertical-disc mills) can be used to produce bulgur particles. Bayram and Öner (2007) showed that the roller mill gave the highest milling yield (99.2%) and produced a smooth and glassy particle surface due to its sharp-to-sharp operational principle. However, uniform particle shape was not obtained from the roller mill. The double-disc mill caused low surface quality in contrast to obtained ovoid or elliptical shape, and the milling yield was lower (94.8%). The vertical-disc mill decreased the retention time of bulgur particles in the milling zone; therefore, the ellipticity (ovoid shape) of the bulgur particles was lower than that from the double-disc mill, and the milling yield was higher (97.6%). The roller-milling system could be improved (Yildirim et al 2008) by using four successive rolls and three gaps. This process delivered a high production yield as well as a high throughput (3,500 kg/h) with low grinding energy consumption (18.5 kJ/kg). It also supplied uniform particle sizes due to multiple milling stages by preventing the escape of kernels from the gaps. The milled samples are then sized to obtain coarse (>3.5 mm), pilaf (2.0–3.5 mm), medium (1.0–2.0 mm), and fine (0.5–1.0 mm) bulgur.

Bulgur remains a staple food in Turkey and the Near East, where it is used as a principal source of energy. According to Williams (1985), an estimated 15% of durum wheat is used to make bulgur. Jenkins et al (1986) concluded that traditional processing of cereals, such as parboiling (as for bulgur) may result in the low glycemic index (GI) values (65 ± 4) associated with the unmilled cereal. Cereal foods processed in these ways may form a useful part of the diet when a reduction in postprandial glycemia is required. Comparing several types of bulgur, Solah et al (2007) stated that bulgur samples provide greater satiety than a high-amylose rice. Bulgur also appears to be a good source of protein and fiber. Whatever the debranning process, Ozboy and Koksel (2001) found that bulgur is at least as good as raw wheat in terms of dietary fiber content (5.4 and 11.5% for acid detergent fiber and neutral detergent fiber, respectively). Kadakal et al (2007) evaluated the processing impact on the water-soluble vitamin content of bulgur (thiamin, niacin, panthothenic acid, pyridoxine, and riboflavin). Both cooking and drying significantly decreased the vitamin content. As the cooking temperature increased, the concentrations of water-soluble vitamins decreased. On the other hand, the decrease in water-soluble vitamins was higher with open-air sun drying than with hot-air oven drying.

Frekeh

The name *frekeh* (or *firik* or *frik*) is given to green, roasted, crushed, and sieved immature durum wheat grain. *Frekeh* is an ancient (probably the parched grain of the Bible) and traditional whole wheat product produced from early harvested wheat at the milky stage, generally using durum wheat (Bayram 2008). In contrast to bulgur, which is prepared on an industrial scale, *frekeh* making is localized at the artisanal scale. Nevertheless, according to Williams and Jaby-El-Haramein (1985), an estimated 300,000 t of *frekeh* is prepared each year in the Middle East. This product also remains very popular in Maghreb, where a kilogram of *frekeh* may cost five to six times the price of a kilogram of semolina.

Traditionally, *frekeh* is prepared from immature grains of durum wheat, especially from cultivars able to give the greenest and largest sized kernels (Elias 1995). The stage at which durum wheat is harvested is critical. The optimum harvesting time corresponds to the filling stage and does not last more than 10 days. The wheat is hand-harvested and arranged in small piles with the spikes facing the wind. Piles are laid to dry in the sun for one day. They are then scorched by flames to burn off the awns and leafy material but not the seeds. After another drying period, the roasted wheat is further threshed to separate the grain from the chaff. The grains undergo a complimentary drying step, preferentially in the shade to avoid bleaching. The seeds are then cracked into smaller pieces so they look like green bulgur and have a smoky distinct flavor.

Few studies have been dedicated to developing the mechanization of *frekeh* production. Most of them were undertaken to improve drying and threshing conditions (Humeid and Al-Amary 1986, Umary and Humeid 1986). The literature on immature cereal grains does not refer to the harvesting issues of this type of product. Regarding the transformation process itself, most of the works deal with the conditions for stabilizing the grain after harvest. Drying conditions were studied for a grain moisture content between 1,000 and 170 g/kg (db) at harvest time. Under their experimental conditions (thin layer), Jayas et al (1988) showed that the rate of drying does not depend upon grain maturity. Clarke (1986) compared drying conditions in the fields with simulated ventilation with hot air (40°C) and with a simply temperature-controlled room. He concluded that oven drying tends to reduce the level and quality of grain, in particular, the value of hectoliter weight. Moreover, the percentage of green grains decreases more quickly when drying with air ventilation is used. The color loss is higher as the harvest date is earlier (Clarke 1989).

Immature cereal grains are traditionally considered to possess good nutritional value. As a consequence or not, *frekeh* is mostly consumed in form of soup during the Ramadan period. Several studies have been conducted on immature wheat grain to characterize the changing composition during maturity. Using near-infrared spectroscopy, Czuchajowska and Pomeranz (1989) analyzed different cultivars at various stages of maturity (7–42 days after flowering). They showed that immature grains are characterized by infrared spectra showing four specific areas, while mature wheat grains show only one specific peak. In addition, these authors observed that the evolution of grain maturity could be followed by the development of a peak (at 2,276–2,288 nm), probably associated with the development of nonstarch polysaccharides. D'Appolonia and MacArthur (1976) confirmed this result by following the evolution of pentosans in the mature grain and specifying that the arabinose-xylose ratio in the endosperm decreases with maturity. D'Egidio et al (1996) compared the composition of durum wheat kernels at milk stage (15 days after flowering) and at maturity. With maturity, starch content increased, whereas the α-amylase activity decreased by about 40%. Fructans and, more specifically, low molecular weight fructo-oligosaccharides decrease dramatically by a factor of seven. Insofar as the end of maturity corresponds to the synthesis of large grains of starch, Karlsson et al (1983) observed that the gelatinization temperature of starch decreases with grain ripening.

As far as protein content is concerned, contrasting results were observed due to variations in the degree of maturity but also to the position of grains on the spike (Huebner et al 1990). The amino acid composition varies with the harvest stage. Indeed, proline, glutamic acid, and phenylalanine increase from the milk stage to maturity, while aspartic acid, lysine, and alanine decrease significantly with the degree of maturity (Humeid et al 1990). Protein synthesis begins with the albumin and globulin and continues with the polymers of higher molecular weight, so that the average molecular weight of proteins increases with grain filling (Stone and Nicolas 1996). However, these changes do not seem to cause differences in the composition of high molecular weight glutenin subunits (Watanabe et al 1996). About vitamin content, Wall and Carpenter (1988) showed that bioavailability of niacin is greater in immature grains, and Takruri et al (1990) concluded that the nutritional value of *frekeh* harvested at milk stage is greater than the similar product obtained from mature seeds. Moreover, according to Merendino et al (2005), feeding rats with immature wheat increases the proliferation rates of lymphocytes, indicating a stimulating effect on the immune response, and decreases the plasma triglycerides and cholesterol levels, indicating a positive effect on lipid profiles, but antioxidant concentrations in blood and lymphocytes did not change significantly.

Other Durum Grain Products

Widely diverse grain products exist all around the Mediterranean area. These ancient and traditional products, which generally rely on what is called Sumerian agriculture, were extensively described by Hillman (1985). Nevertheless, new products also have been developed in innovative ways to answer consumer expectations. An example of such an innovation (Fig. 10.1) is the commercial development of a product named Ebly (Grenet et al 1993). The associated process allows the use of durum wheat as whole grains, like rice. In this case, rehydration is not facilitated by crushing the grain but by a specific process to control grain expansion. This process creates a microporous structure that reduces the preparation time to only 10 min.

In the same way as for the bulgur process, grains are first precooked (at <100°C) to gelatinize the starch and then are dried to obtain a very highly vitreous endosperm. Grain is debranned to remove the pericarp but not the aleurone layer. These outermost layers give the final product an unpleasant fibrous texture and must be eliminated. During this operation, a part of the germ is also removed because its rancidity would be detrimental to the shelf life of the end product. Nevertheless, a major part of the aleurone layer is preserved so that the product qualifies as a

Fig. 10.1. The commercial product Ebly, an expanded whole durum grain. © LIBERT P. (Courtesy INRA)

good source of fiber without diminishing the organoleptic quality. The final expansion is performed by heat treatment at high temperature (>200°C) for a short time (the high-temperature, short-time method). The controlled expansion process (the grain volume increases only 30%) results in a precooked grain with a microporous structure in a dense network, allowing the product to rehydrate very quickly (in 10 min by immersion in boiling water), without changing its cooking quality.

Because of the potential nutritional quality of immature grain (D'Egidio and Cecchini 1998), a new whole-durum immature grain with the brand name of Grinn's was developed by Abecassis et al (2005). They developed an appropriate harvesting system that enabled the collection of almost all green seeds. At this stage, whole grains are mainly covered by their hulls. A cleaning procedure was designed to extract the immature seeds from the ear while preserving their physical integrity. Achieving this extraction without using desiccation enabled the development of plant products similar to sweet corn kernels derived from wheat seeds harvested before they were ripe. Then a hydrothermal treatment was developed with the aim of retaining the green color of the seeds, preventing the development of unpleasant flavors due to the action of oxidative enzymes, and obtaining an adequate texture of the cooked product, taking into account the presence of hulls naturally present in whole grains. The end product is packed in flexible pouches and can be prepared in less than 2 min in a microwave oven.

SEMOLINA AGGLOMERATION IN THE FORM OF COUSCOUS

Couscous is a very ancestral food product, nearly 2,000 years old. The invention of couscous goes back to Roman times; it was invented in North Africa by the Berbers. Couscous was spread by the Arabs throughout Europe in the seventeenth century and moved to the Americas with the Portuguese cargoes from Morocco. Couscous is also widely known around the world because of the growing popularity of healthier eating and the "Mediterranean diet." It can be consumed in various recipes: salads, like tabouli, or traditional couscous dishes. The simplicity of the product and its versatility and convenience are among the reasons for its popularity. Couscous has crossed the borders of tradition and ethnicity to become a trendy and modern food.

The *Codex Alimentarius* (Codex Standard 202-1995) defines couscous as

> the product prepared from coarse and fine durum wheat semolina (*T. durum*), the elements of which are bound by adding potable water which has undergone physical treatment such as cooking and drying.

Compared to those on pasta products, there are only a few studies on the processing and mechanisms underlying couscous quality (Kaulp and Walker 1986, Dick and Matsuo 1988, Quaglia 1988, Guezlane and Abecassis 1991, Guezlane 1993, Debbouz et al 1994, Debbouz and Donnelly 1996, Hébrard et al 2003a, Cuq and Abecassis 2006, Ounane et al 2006). Couscous quality has been found to depend on both the raw material characteristics (durum wheat grain characteristics and milling conditions) and the manufacturing process (more particularly, the agglomeration, cooking, and drying stages). In the present chapter, we first describe the main attributes that are classically used to evaluate couscous quality. The contributions of raw materials and the manufacturing process to the physicochemical mechanisms involved during couscous making (from raw material to end product) and to the quality attributes of couscous products are presented.

Couscous Attributes of Quality

Couscous of "good quality" is an amber-yellow product with a high water-absorption capacity and the ability to hold together, stay distinct, be firm, and have good taste when hydrated. Quality parameters for couscous can be presented at three levels: 1) characteristics of dry couscous grains, 2) quality parameters related to rehydration behavior (before consumption), and 3) quality parameters related to consumption.

CHARACTERISTICS OF DRY COUSCOUS GRAINS

The characteristics of dry couscous grains are described by its composition, color, and physical properties.

Composition. The *Codex Alimentarius* (Codex Standard 202-1995) indicates that the moisture content of couscous shall not exceed 13.5% and its ash content maximum shall be 1.1%. No food additives shall be added during the industrial processing of couscous. The maximum value of the moisture content is a legal definition and is also required to obtain low water activity to ensure product shelf life. The biochemical composition of couscous (Table 10.1) is close to that of the durum wheat semolina that is used as the raw material. As expected, couscous processing does not change the starch (85–86%), protein (13.5%), and pentosan (1.4–1.7%) contents. On the other hand, one observes large differences in component characteristics due to the physicochemical changes induced by the manufacturing process. Couscous is characterized by low values of soluble protein content (2.2%) and high values of gelatinized starch content (71.8%), in comparison with durum wheat semolina values (12.7 and 5.9%, respectively). During couscous processing, semolina should be hydrated with water or with a salt-water solution at 4–5 g of NaCl per liter. The residual chloride content of couscous is about 3 mg/g (Kaulp and Walker 1986). However, no studies have demonstrated the possible effects of the added salt on gluten toughening and texture properties of couscous.

TABLE 10.1
Classical Values Observed for the Biochemical Composition of Durum Wheat Semolina and Industrial Couscous

Composition	Durum Wheat Semolina	Medium Couscous
Water content (g/100 g product)	14.5 (± 0.4)	9.8 (± 0.3)
Starch content (g/100 g dry matter)	86.2 (± 6.0)	85.6 (± 6.0)
Gelatinized starch content (g/100 g dry matter)	5.9 (± 0.3)	71.8 (± 3.6)
Total protein content (g/100 g dry matter)	13.5 (± 0.5)	13.5 (± 0.5)
Soluble protein content (g/100 g dry matter)	12.7 (± 0.6)	2.2 (± 0.1)
Total pentosan content (g/100 g dry matter)	1.7 (± 0.2	1.4 (± 0.1)
Soluble pentosan content (g/100 g dry matter)	0.1	0

Color Parameters. Couscous grains are characterized by a light yellow color. Guezlane (1993) indicated that the color of couscous depends mainly on the characteristics of the durum wheat semolina and little on the process factors. Color characteristics of couscous have ranges of 27–45 for the yellow hue (b^*), 21–72 for the brightness (L^*), and 0–4 for the red hue (a^*) (Guezlane 1993, Debbouz et al 1994, Debbouz and Donnelly 1996). Homemade couscous was found to be characterized by slightly higher values of L^* (71.3) and b^* (30.7) than industrial couscous ($L^* = 68.9$ and $b^* = 27.1$) because homemade couscous loses less carotenoid pigment during processing (Guezlane et al 1986, Debbouz and Donnelly 1996).

Particle Size. The *Codex Alimentarius* (Codex Standard 202-1995) indicates that couscous granularity must range between 630 and 2,000 µm, with a tolerance of 6%. Industrial couscous is usually sold in three different types according to grain size: fine, medium, and coarse. A description of couscous granularity should be considered through particle-size distribution curves, as illustrated in Figure 10.2 for homemade and medium-sized industrial couscous. Mean diameter values for homemade couscous grains (d_{50} = 800 µm) are lower than those for medium industrial couscous (Fig. 10.2). Homemade couscous is close to fine industrial couscous. A relatively large dispersion in particle size around the mean diameter ($d_{84}/d_{50} = 1.30$) is observed for couscous grains.

Particle Shape. The almost spherical shape of couscous grains can be seen using scanning electron micrographs. Homemade couscous grains are irregular particles, with a more-or-less spherical shape and rough surface. Industrial couscous grains are more-regular particles, with a more-homogeneous and spherical shape and smooth surface. Guezlane (1993) quantified the shape of couscous grains using image analysis and evaluated several shape parameters. From a set of about 10 industrial and homemade couscous samples, the almost spherical shape of couscous grains was described by a low dispersion of circularity factor (0.68–0.73) and elongation factor (0.70–0.74).

Particle Microstructure. Scanning electron micrographs have also been used to evaluate the microstructure of couscous grains (Fig. 10.3). Dry couscous grains appear as agglomerated large particles, built by the association of more-or-less molten initial small semolina particles (300–500 µm). The rigidity of the couscous grains is due to the molten bridges between the agglomerated small initial particles. The presence of a residual vacuum between the more-or-less molten semolina particles allows some porosity inside the couscous grains.

The bulk density of couscous has been measured by filling a graduated cylinder (Guezlane 1993, Debbouz and Donnelly 1996). Values of bulk density range between 0.60 g/cm^3 for homemade couscous and 0.79 g/cm^3 for industrial couscous. The bulk density of couscous depends both on the compactness of the grains (true density) and on the vacuum ratio between the grains (due to their size and shape distribution).

QUALITY PARAMETERS RELATED TO REHYDRATION BEHAVIOR (BEFORE CONSUMPTION)

Good-quality couscous grains must be characterized by a high ability for water or sauce absorption. The extent to which couscous grains absorb water affects the taste as well as the mouthfeel. If couscous does not absorb the water adequately, it feels hard and lacks the desired smoothness. The cold and/or hot water absorption behavior of dry couscous grains can be evaluated with three parameters: time for water absorption, water solubility index, and water absorption index.

Time for Water Absorption. This time is evaluated by mixing dry couscous and water and measuring the time required for all the water to be completely absorbed by the grains (Debbouz et al 1994, Debbouz and Donnelly 1996). Classical values of optimum rehydration time range between 10 and 16 min. Differences in rehydration time values could be associated with differences in grain compactness.

Water Solubility Index. This index expresses the extent of couscous disintegration during water absorption. It is measured as the amount of solids that is solubilized during immersion of a couscous sample in an excess of water (Debbouz et al 1994, Ounane et al 2006). The amount of soluble materials leached out in water has been related to couscous stickiness; low values of water solubility index are indicative of high-quality products. Classical values of water solubility index range between 4 and 16%.

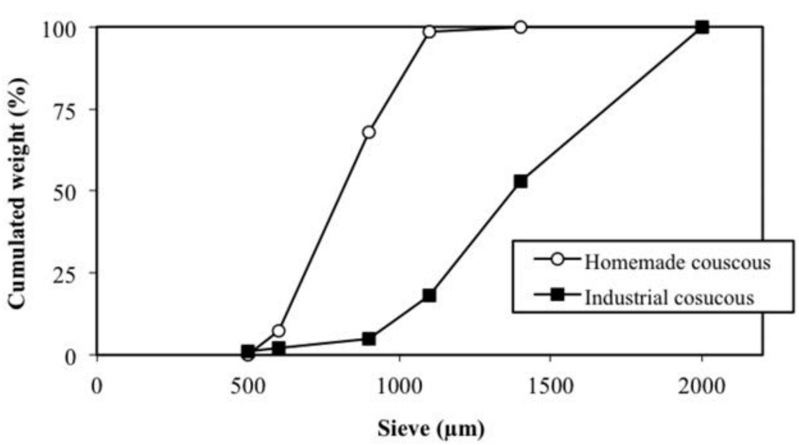

Fig. 10.2. Typical particle size distribution for medium-sized industrial couscous and homemade couscous.

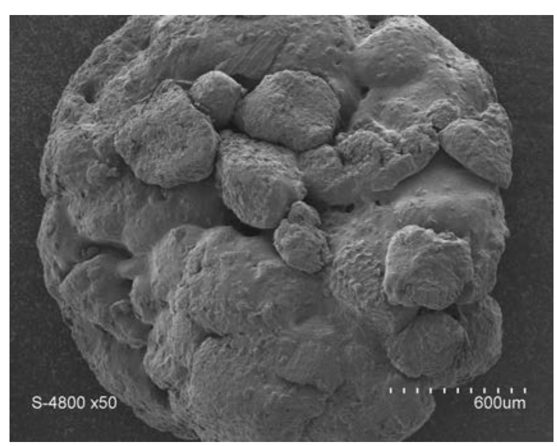

Fig. 10.3. Scanning electron microstructure of couscous grain.

Water Absorption Index. This index is measured as the change in weight of a sample of couscous when immersed in an excess of water at 30°C (Debbouz et al 1994). Typical values of water absorption index range between 460 and 490 g of water per 100 g of couscous. Debbouz (1992) found a high correlation ($r = 0.90$) between water absorption index and extent of starch gelatinization in couscous grains.

Swelling. Swelling of couscous is measured by the changes in apparent volume of a sample of couscous when immersed in cold (at 25°C) or hot (at 100°C) water (Guezlane and Abecassis 1991, Guezlane 1993, Ounane et al 2006). This characteristic depends on the water absorption index as well as the ability of the hydrated couscous particles to resist compaction. High values of couscous swelling are indicative of a high-quality product. Typical values of swelling are 280–320 mL/100 g of couscous at 25°C and 380–410 mL/100 g of couscous at 100°C. Ounane et al (2006) indicated that couscous swelling at 100°C is partly correlated with the water solubility index ($r = 0.55$).

QUALITY ATTRIBUTES RELATED TO CONSUMPTION

Couscous of good quality after water is added can be defined as an unsticky product of good cooked flavor and mouthfeel. The quality parameters related to consumption are based on stickiness, caking index, sensory attributes, and texture properties.

Stickiness. Stickiness is related to the surface characteristics of couscous grains after rehydration. It is measured using a texture analyzer according to a method that was used for pasta (Debbouz et al 1994, Debbouz and Donnelly 1996). Low values of couscous stickiness are indicative of a high-quality product. When couscous grains are steam cooked, some exudates due to starch gelatinization can migrate to the surface of the grains and generate couscous stickiness. The high correlation between semolina starch damage and couscous stickiness ($r = 0.90$) might be related to the amount of solubilized material covering the surface of the cooked couscous grains.

Caking Index. This index is related to an agglomeration phenomena of the couscous grains after rehydration (Guezlane 1993, Ounane et al 2006). The caking index of couscous can be evaluated by a sieving method after hydration and drying. Low values of couscous caking index are indicative of a high-quality product. Ounane et al (2006) found caking index values ranging between 8.2 and 32.6%. A negative correlation ($r = -0.59$) was found between the caking index and the initial particle size (d_{50}) of dry couscous.

Texture Properties. The texture of cooked couscous can be evaluated with a compression method classically used for pasta products (Yettou et al 1997, Ounane et al 2006). These authors assessed texture properties of couscous on the basis of firmness (5.79–7.53 mm), elastic recovery (0.3–0.8 mm), and viscoelasticity index (1.3–1.9). Low values of firmness and viscoelasticity index are indicative of a high-quality product. However, the texture properties are poorly correlated with the sensory attributes (Guezlane 1993).

Sensory Attributes. Sensory attributes of couscous can be evaluated by panels of judges using various parameters: appearance, mouthfeel, flavor, and overall acceptability (Kaulp and Walker 1986, Debbouz et al 1994, Debbouz and Donnelly 1996).

Raw Materials for Couscous Production

Durum wheat semolina is the "traditional" raw material used in the manufacture of couscous. It was first thought that the semolina requirements for couscous were similar to those for pasta products (Kaulp and Walker 1986). However, Quaglia (1988) demonstrated that the high-grade semolina used for pasta is not a requirement for couscous production and that lower-grade semolina can be used. It is now known that the characteristics of durum wheat semolina play a moderate role in the adjustment of couscous processing conditions and in defining the quality of the end product. However, only a few studies have investigated the influence of semolina characteristics (biochemical and physicochemical properties) on couscous quality.

The color of couscous grains largely depends on the initial color of the durum wheat semolina. Nevertheless, granulometry of the final product also greatly affects its color. The presence of bleaching enzymes (lipoxygenase) in the raw material can affect couscous color by reducing yellowness (Debbouz et al 1994).

The particle size of semolina plays a role in defining the process settings during couscous making. Because of its higher water absorption, fine semolina requires more water during mixing than does coarse semolina. However, fine semolina results in lower couscous yield than medium or coarse semolina. This is especially true when couscous is rolled by hand, because large amounts of the oversized wet agglomerates that are formed with fine semolina are discarded. During the steam-cooking stage, water absorption by the couscous grains may be more important for fine semolina, because it contains more damaged starch than coarse semolina (Quaglia 1988). The particle size of semolina also contributes to the end-product qualities. Debbouz et al (1994) found that an increase in semolina particle size induces a slight decrease in couscous brightness (L^*). They also indicated that rehydration time of dry couscous grain decreases as particle size of semolina decreases, and they supposed that the fine semolina particles rehydrate more rapidly than do coarse semolina particles. Using fine semolina gives stickier couscous grains than using coarse semolina.

The contribution of wheat proteins to the performance of semolina during couscous making has not been adequately investigated. Quaglia (1988) hypothesized that the raw material of choice for couscous making is durum wheat semolina with high gluten and protein contents. Couscous yield has been closely associated with gluten quality and protein content. Debbouz et al (1994) suggested that strong-gluten cultivars gave significantly higher couscous yield than weak-gluten cultivars. Higher rehydration times were found for weak than for strong gluten cultivars. The strong varietal influence on couscous rehydration time was attributed to the effect of gluten quality. Debbouz et al (1994) found that couscous stickiness decreased as semolina protein content increased. On the other hand, Ounane et al (2006) showed that couscous quality was not affected by the semolina protein characteristics when couscous was evaluated using the mixograph.

Ounane et al (2006) found that the cooking quality of couscous made from different durum wheat semolinas was partially dependent on the semolina's free-lipid content and composition. Even if no correlation was demonstrated between cooked couscous quality and the total lipid content of semolina ($r < 0.3$), the nonpolar lipid content was correlated with the surface state of couscous grains, as evaluated by the caking index ($r = -0.48$) and water solubility index ($r = -0.54$). Polar lipids of semolina were found to affect couscous firmness ($r = 0.57$). Polar bound lipids contributed to couscous swelling ($r = 0.53$) and to caking index ($r = 0.70$).

Couscous Processing

Traditional couscous is made by hand. Durum wheat semolina is moistened with water in a dish and stirred by hand. The moist bulk is rubbed with the palm of the hand to form small spherical granules compressed between the hand and the container and is compacted by successive throws and drops for about 15 min. Forcing the granules through a metal sieve can accelerate the compression and allows the formed granules to be calibrated at the same time. The hydrated particles are then cooked with vapor. Steam is generated over boiling water and passes through a covered thick layer (10–20 cm) of raw couscous for 20–30 min. After cooking, couscous particles are dried and stored. During the dry summer months, they can be sun-dried on the flat roofs of houses.

The first attempts to industrialize couscous production were initiated in the 1960s in North Africa, with the transposition of technologies of the pasta industry to couscous manufacture. It was not until the mid 1970s that fully automated couscous production lines started in France and later in other parts of the world. Rates of industrial lines for couscous processing range from 500 to 1,200 kg/h. The design of the industrial equipment for couscous production should imitate the technique of and reach the final qualities of homemade couscous (Kaulp and Walker 1986, Quaglia 1988, Méot 2006). However, the majority of the current production lines remain only improvements of the initial process. Indeed, the limited commercial stakes of the couscous industry did not encourage companies and equipment suppliers to invest significantly in improving the industrial process and developing specific equipment and monitoring probes. In addition, the scarcity of technical and scientific works available (about 15–20 publications and patents) contribute to the relative "empiricism" in the design and management of couscous production, which has restricted potential innovations of the process. The mechanisms involved in couscous processing are still partly unknown.

From durum wheat semolina, the main unit operations involved in couscous processing can be described as three successive stages (Fig. 10.4):

Stage 1 corresponds to the formation of calibrated moist couscous grains by a wet agglomeration process through wetting, mixing, rolling, and sieving unit operations.

Stage 2 corresponds to heat treatment of the moist couscous grains by steam cooking in order to strengthen the structure and gelatinize the starch.

Stage 3 corresponds to the stabilization of the cooked couscous grains by a drying process to ensure the shelf life of the dried couscous grains.

When compared with pasta making, the couscous process displays two specific aspects.

Couscous processing is fully a "powder process," from the raw materials (durum wheat semolina) to intermediate products (raw and cooked couscous grains) and end products (dried couscous grains). The powdered structures require specific mechanisms for couscous grain formation.

Couscous processing requires size-classification operations after the rolling stage and drying stages (Fig. 10.4). These sieving operations generate flows of out-of-scope products (too fine or too large), which must be recycled (Hébrard 2002).

PARTICLE AGGLOMERATION (WETTING, MIXING, AND ROLLING)

The first stage in couscous processing is the agglomeration stage, during which durum wheat semolina particles (d_{50} = 300 µm) are transformed into large wet agglomerates (d_{50} = 1,150 µm), the "raw couscous grains." Agglomeration is a critical stage during couscous processing for two reasons: 1) the characteristics of the wet agglomerates (size distribution, density, and shape) greatly contribute to the qualities of the final couscous grains, and 2) the agglomeration stage directly controls the performance of the couscous production line, particularly because this stage generates large amounts of recyclings (three times the initial semolina flow rate, Fig. 10.4).

To agglomerate the initial durum wheat semolina particles, two elements must be added, water and mechanical energy. A

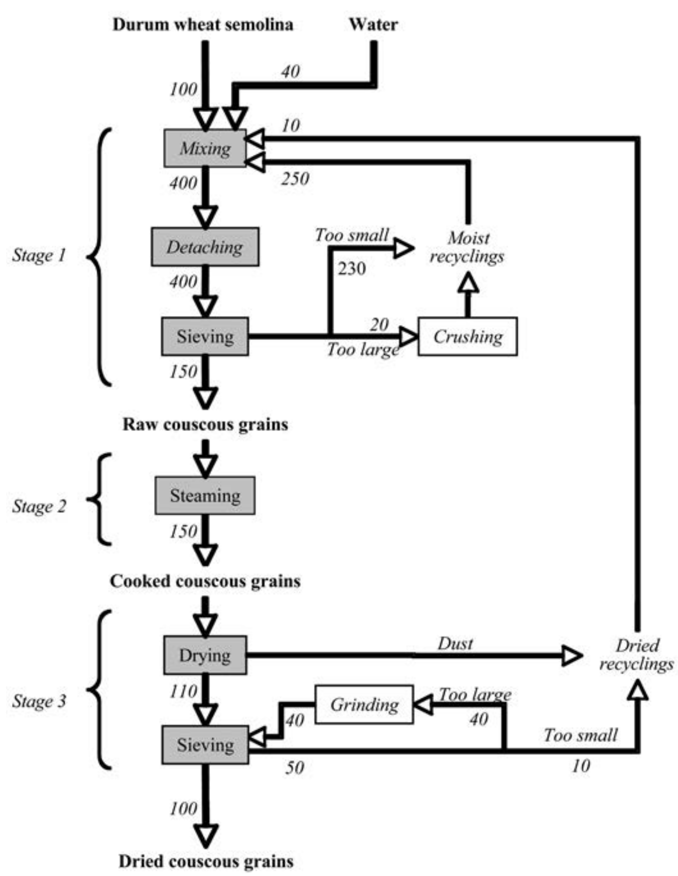

Fig. 10.4. Process diagram for couscous production. (Values are apparent product flow rates, assuming a theoretical durum wheat semolina flow rate of 100.)

specific proportion of water is required to form enough stable bonds between the semolina particles. Mechanical energy must be added to agitate the powder-water mass so as to homogenize water dispersion and promote agglomerate growth. Mixer agglomeration circuits for couscous have been historically designed and run with minimal scientific input, some empirical engineering, but mostly by art. This has created difficulties in predicting and explaining differences in observed behaviors.

In recent years, there has been rapid advancement in the understanding of the fundamental mechanisms and processes that control agitated wet granulation behavior and agglomerate properties for many nonfood applications (Iveson et al 2001, Litster and Ennis 2004). The application of this approach to couscous processing describes three successive phases in the agglomeration process: Phase 1, semolina wetting and agglomerate formation, Phase 2, agglomerate strengthening (mixing and rolling), and Phase 3, agglomerate size classification (sieving).

Semolina Wetting and Agglomerate Formation. The mechanisms of this process are complex because several competing phenomena occur simultaneously. Two types of agglomeration mechanisms must be considered: 1) those based on nucleation, with the simultaneous phenomena of particle wetting and agglomerate formation and 2) those based on coalescence, with the successive phenomena of an initial phase of particle wetting followed by a phase of agglomerate formation.

Nucleation. The formation of agglomerates by nucleation (i.e., the "drop-controlled regime") is mainly based on the fall of "large" water drops directly onto the bed of semolina particles, which generates the formation of a nucleus (Fig. 10.5). This type of agglomeration mechanism can be observed during the home-making couscous manufacture and inside classical horizontal mixers (equipped with wetting systems and rotating blades) in industrial couscous production lines. Nucleation occurs directly inside the tank of the mixer, at the level of the water-addition zone. When water falls down over semolina at the beginning of the mixing zone (Fig. 10.5), one observes the instantaneous formation of agglomerates of very heterogeneous sizes.

In the drop-controlled regime, the size of water drops is larger than the size of initial semolina particles (Fig. 10.5). In these conditions, formation of the nuclei mainly depends on physical mechanisms (Iveson et al 2001). Nuclei can be considered as spontaneous assemblies of particles of semolina, which are stabilized by liquid (water) bridges. In the water-spray zone, the water drops penetrate into the powder bed pores almost immediately, and the nuclei size distribution mainly reflects the water-drop size distribution. In this zone, one water drop tends to form one wet agglomerate, provided that two key conditions are satisfied: 1) the powder flow through the water-spray zone must be fast enough so that water drops that hit the powder surface do not overlap, and 2) the water drop must wet into the bed completely before mixing brings it into contact with another partially absorbed drop on the bed surface (i.e., the drop penetration time must be fast).

Immediately after water-drop addition and nuclei formation, some secondary physicochemical mechanisms could occur inside the nuclei due to kinetic reactions and the mechanical action of the mixer blades. Mechanical energy input by the mixer is needed to obtain homogeneous nuclei, by forcing the water to be distributed over the powder bed. At the surface of the semolina particles forming nuclei, some solubilization of soluble

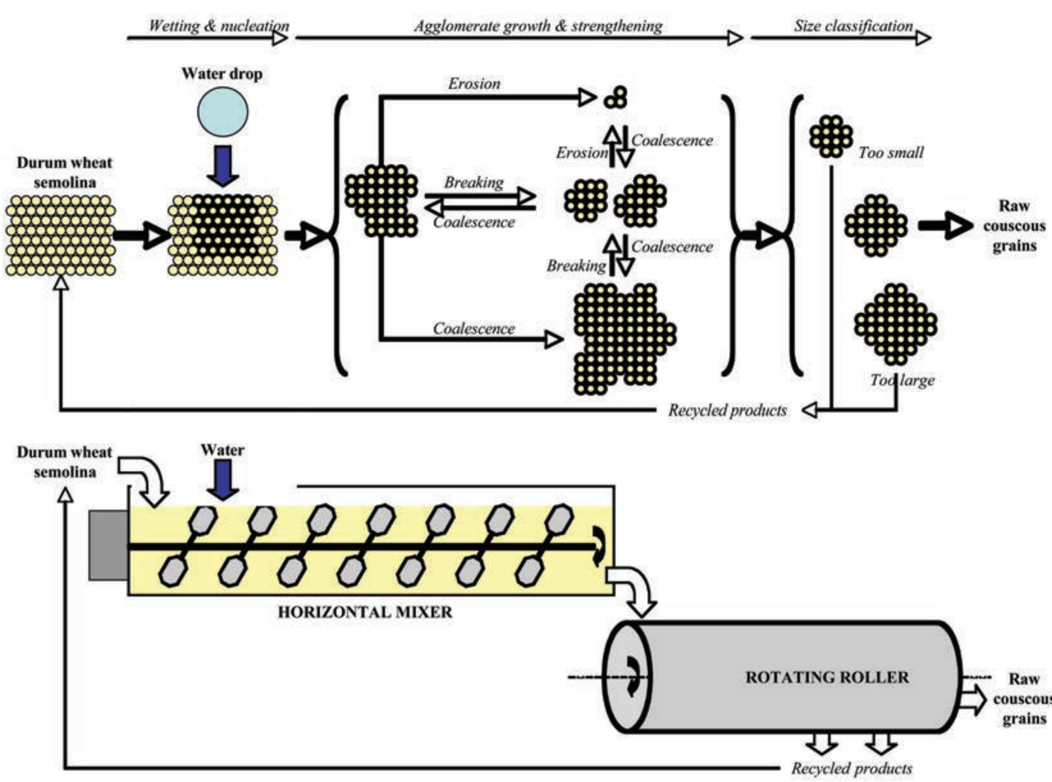

Fig. 10.5. Schematic representation of the classical wetting-mixing equipment used to agglomerate semolina.

wheat components into the water forming the liquid bridges might occur. This solubilization would contribute to the stabilization of the liquid bridges between the semolina particles by increasing the viscosity. Inside the semolina particles forming the nuclei, one can suppose that water diffusion occurs from the surface to the center of the semolina particles. The kinetic phenomenon of water diffusion allows the hydration of wheat components within the semolina particles.

In the drop-controlled regime, the main process parameters that can be adjusted are mixer blade geometry, blade rotation speed, and water addition conditions (area of the water-spray zone, water-drop size, etc.). Hébrard (2002) has studied the influence of mixing conditions (i.e., water-drop size, mixing temperature, number of revolutions of the mixer blade, mixer filling level) on the formation of wet agglomerates. The mean size of the wet agglomerates was found to depend primarily on the size of the water drops. A decrease in size of the water drops (by pulverization rather than in the shape of drops) makes it possible to decrease the fraction of large agglomerates and increase the fraction of raw couscous grains (yield).

Coalescence. The formation of agglomerates by coalescence is based on decoupling semolina agglomeration in two successive phases: a first phase of individual wetting of the semolina particles and a second phase in which hydrated semolina particles form agglomerates (by coalescence) through mixing actions (Fig. 10.6). This kind of agglomeration mechanism by coalescence is observed when using the centrifugal wetting equipment first designed for the pasta-products industry (Hébrard 2002). The individual wetting of the semolina particles requires sufficient mechanical energy input to disperse and individualize the semolina particles before water addition (i.e., the mechanical-dispersion mode). The drop size of the water flow should be sufficiently "small" compared to the semolina particle size, so that the liquid can individually coat each particle (Iveson et al 2001). The particle wetting occurs after collision between the small water drop and the particle, followed by spreading of the liquid over the particle surface. The water-delivery method (water-drop size, nozzle height, etc.) has a minimal effect on the nuclei properties. Very short residence times (less than 1 s) are required to hydrate the surface of particles inside the centrifugal wetting equipment. This equipment allows homogeneous distribution of water on the surface of the particles.

The initial wetting phase of the particles is followed by a resting period (on a rest conveyor) to allow the diffusion of water inside the semolina particles. Water diffusion induces an increase in water content that activates the residual enzymes of semolina and allows the passage of the glass transition for the wheat components, due to water content increase at constant temperature. The formation of agglomerates by coalescence occurs later, through mechanical agitation in the mixer. The mechanical energy input by the mixer generates shocks and contacts between the hydrated semolina particles, which undergo plastic deformation. When the pressure between two particles is high enough, interactions are created between surfaces of the particles, and thus agglomerates are formed. Particle mechanics (yield strength and resistance to deformation) have then to be considered to understand why two particles could rebound or stick together and coalesce. Hydrated particles are plastoelastic material. The Stockes deformation number (defined as a function of the granule yield stress compared to the kinetic energy

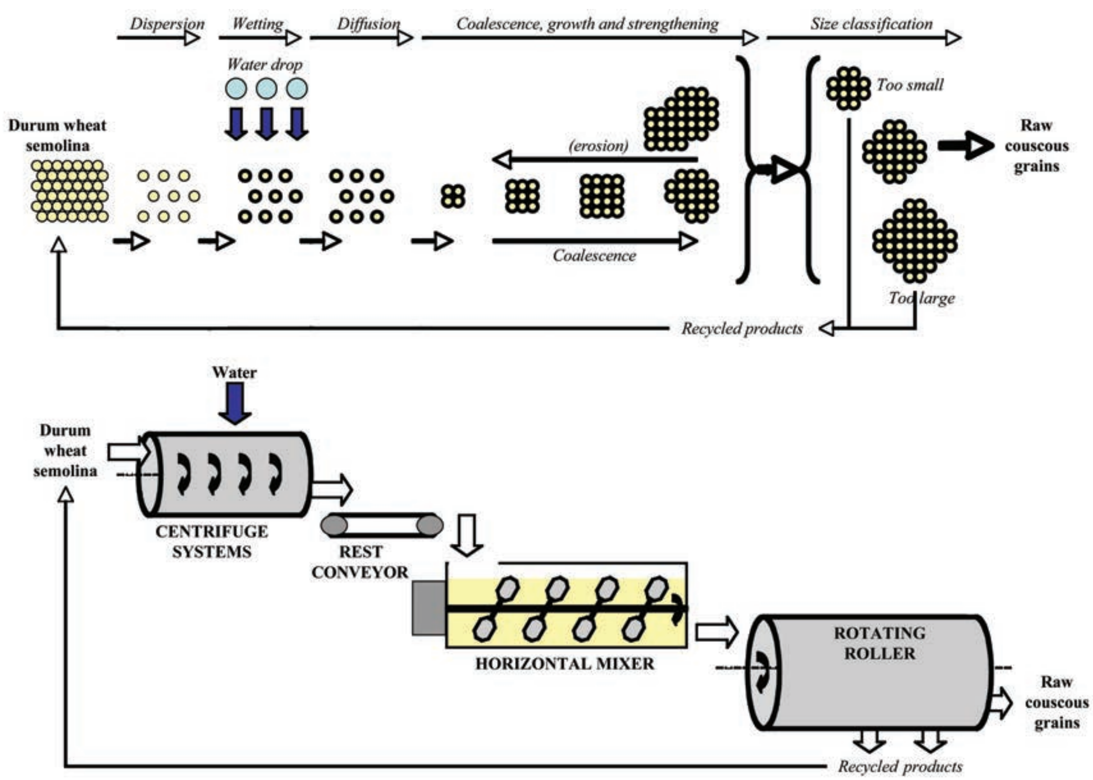

Fig. 10.6. Schematic representation of the centrifugal wetting system equipment used to agglomerate semolina.

absorbed plastically during the collision) can be used to describe the deformation of a particle during its impact in the mixer (Iveson et al 2001).

Hébrard (2002) evaluated the potential of the centrifugal wetting equipment combined with a rest conveyor during couscous processing. In comparison with the traditional wetting-mixing system, the use of centrifugal wetting equipment with a rest conveyor leads to better control of the agglomeration yield, and the size distribution of the wet agglomerates is more uniform. Consequently, agglomeration yield can be twofold higher, and recycled flow is decreased due to lower quantities of fine agglomerates.

The moisture rate and the water diffusion inside semolina particles is of paramount importance in controlling the agglomeration process. A specific water addition level must be used to obtain the right agglomeration conditions of the semolina particles for couscous processing. The optimal water content ranges from about 30 to 40%, depending on the raw materials' qualities (Quaglia 1988, Hébrard 2002, Ounane et al 2006). On one hand, water content must be sufficiently low to avoid dough formation. On the other hand, water content should be high enough to allow gelatinization of the starch granules during the steam treatment. The water content of the wet agglomerates after mixing is critical during the following stage of steam cooking because that stage does not significantly change the water content. It should also be noticed that the amount of water added at mixing can affect the clearness (L^*) of the final couscous grains (Guezlane 1993). The precise knowledge of the kinetics of water transport within semolina particles is a prerequisite for the optimization of couscous agglomeration. The time necessary for water diffusion to hydrate the center of the semolina particles depends on the characteristics of the particles: particle diameter and diffusion coefficient of water. The time for water diffusion is also controlled by process conditions: water content, temperature, etc. Kang and Delwiche (1999) studied the water uptake kinetics of durum wheat samples at 22°C and found a diffusion coefficient of 0.73×10^{-10} m^2/s by numerical modeling of the moisture diffusion using a finite-element model. Kratzer (2007) proposed a method to estimate a diffusion coefficient of water in durum endosperm by using numerical simulation based on a diffusion model. Diffusion coefficients were found between 0.43×10^{-10} and 1.0×10^{-10} m^2/s, with an overall mean of 0.76×10^{-10} m^2/s. Short processing times during the agglomeration stage could result in residual gradients in water distribution within semolina particles. Méot (2006) used a low diffusion coefficient (10^{-9} m^2/s) to calculate an equilibrium hydration time, estimated to be between 1 and 5 min, for semolina particles at 25°C. Hébrard et al (2003b) did not identify any significant effect of particle size on the water adsorption kinetics of durum wheat semolina.

Agglomerate Strengthening (Mixing and Rolling). Immediately after the initial phase of agglomerate formation (by nucleation or by coalescence), a phase of strengthening of the wet agglomerates occurs. This phase is critical to obtaining the right size of the agglomerates and to homogenizing the size distribution of the agglomerates so that stabilized grains can be obtained. The strengthening phase is conducted through moderated mechanical energy input both during the end of the mixing stage and in the rolling stage (Fig. 10.6). The mechanical energy input during the mixing and rolling stages can induce some changes in the internal structure of the wet agglomerates through compression phenomena to consolidate the structure and increase the density by packing. Solid bridges between particles and solubilization of some wheat components between particles that stabilize the water-liquid bridges and consolidate particle-particle interactions are thought to occur inside the agglomerates.

The mechanical energy input during the mixing (10–20 min) can also induce significant changes in the size of the agglomerates. This period aims at lowering the number of fine agglomerates (and individual semolina particles) by properly regulating the rotating mixing blades and the number of rotations. Due to coalescence mechanisms, very large agglomerates could also be generated inside the mixer, but some decrease in size of agglomerates by surface erosion or breakage into several parts can occur. After the mixing stage, the wet agglomerates are discharged into the detacher to separate the overly large, entangled agglomerates (Debbouz and Donnelly 1996).

For the rolling stage, two technologies are available: rolling over a vibrating sifter (i.e., plansifter) and rolling in a drum roller. For the rotating rollers, the first section is a nonperforated metal sheet that allows compression, rolling, and, to a lesser extent, compacting of the wet agglomerates. The adjustment parameters of the roller/sifter are choice of screens sizes, roller lengths, and rotation speed. Guezlane (1993) indicated that the hydration level at mixing should be adjusted as a function of the rolling conditions. Slightly higher water contents are required when using a rotating roller than when using a sifter. Hébrard (2002) did not find any significant influence of the rolling conditions (using a vibrating sifter) on the characteristics of the agglomerates (size, density, form). Hébrard (2002) showed that the shape of the agglomerates obtained after mixing is not significantly modified by the sifter. On the other hand, the rotating effect inside the roller is thought to contribute to the spherical shape of the wet agglomerates. Indeed, the couscous grains formed in a rotating roller are more spherical and dense than those formed in a sifter, which display more irregular form (Hébrard 2002).

Agglomerate Size Classification. Size classification of the wet agglomerates is the second function of the rolling stage. The screening stage (inside the vibrating sifter or the rotating roller) must remove the oversized agglomerates and the overly fine particles. With rotating rollers, after the first nonperforated metal sheet section, the perforated sheets with small holes remove agglomerates that are too small. After that, perforated sheets with holes allow the agglomerates with the required diameter to be selected. The larger agglomerates are sent to the end of the roller.

Guezlane (1993) indicated that the choice of rolling technique (vibrating sifter or rotating roller) could have an influence on the screening yield. Under laboratory conditions, the use of a vibrating sifter seems to favor a lower proportion of the too-large agglomerates. These agglomerates are sent into a crushing system and then recycled directly in the mixer, while the too-small agglomerates could be rehydrated before mixing. All the recyclings are thus considered raw material and are mixed with the durum wheat semolina. The size calibration function of the roller has a particular importance, because if the rejection process is not properly carried out, the efficiency of the process is impaired due to excessively large quantities of recyclings. After the screening stage, the wet agglomerates of the required diameter are considered “raw couscous grains.”

STEAM COOKING

Raw couscous grains then reach the second stage of couscous processing (Fig. 10.4), the steam cooking treatment. The selected products (medium or fine raw couscous grains) are distributed directly to a conveyor belt cooker for continuous steam treatment. Steam cooking is conducted at temperatures around 100°C at atmospheric pressure. Raw couscous grains are spread in a layer 8–12 cm thick, and about 500–800 g of steam is used per kilogram of dry couscous (Quaglia 1988; Guezlane et al 1998a,b; Méot 2006; Ounane et al 2006). To take into account the heat transfer inside the thick product layer, the residence time in the steam cooker (12–18 min) is much higher than the time required to cook the raw couscous grains (about 1.5 min). Several cooking parameters can be adjusted, such as residence time, thickness of the layer, and steam flow. During the steam cooking treatment, some water condensation occurs and causes couscous grains to stick together (caking), making them more difficult to separate. However, the couscous grains absorb relatively low quantities of steam (only 8–10% by weight). The water content of the cooked couscous grains is approximately 32% wet basis (Guezlane et al 1998b). The cooked grains should then be broken up and partly disaggregated in a separator and calibrated through a sieve, before being sent in a flowable state to the dryer (Quaglia 1988, Méot 2006, Ounane et al 2006).

The cooking treatment induces significant physicochemical changes of the wheat components of the couscous grains. The initial function of the cooking stage is to gelatinize the starch granules. At the cooker’s inlet, the raw couscous grains are moist enough (about 32%) to allow wheat starch to gelatinize at the cooking temperature (100°C). The starch granules lose their initial semicrystalline configuration (Guezlane et al 1998a). The degree of starch gelatinized is about 55–60% at the completion of cooking (Debbouz and Donnelly 1996). The extent of changes in starch structure through gelatinization has been found to control the water absorption, swelling capacity, and caking properties of the final couscous grains (Guezlane 1993). Partial solubilization of the amylose chains extending out of the granules is also supposed to occur and could thus contribute to the formation of very solid links between the particles inside the grains. The cooking stage thus plays a very important role in the solidification of the couscous grains. If uncooked, the couscous grains break down into dust during drying, handling, packing, and transport (Méot 2006).

The cooking stage also induces the formation of amylose-lipid complexes (Guezlane et al 1998a). Under the steam treatment, the amylose starch chain should form complexes with the wheat monoglycerides. The proportion of amylose-lipid complex increases with cooking time. However, because the quantity of wheat lipids is limited, the phenomenon quickly stops. The formation of the amylose-lipid complexes is thought to be responsible for some of the properties of cooked couscous grains, such as low stickiness (after hydration of the dry couscous grains) and the lack of retrogradation mechanisms during storage. The cooking stage plays a very important role in avoiding unexpected agglomeration of the final couscous grains when hydrated before consumption (Guezlane et al 1998a). Without the cooking stage, the couscous grains could be very sticky. These effects are in accord with traditional practices for couscous preparation (i.e., during traditional couscous making, the product is subjected to two successive cooking periods, with fat addition after the first cooking period). Belaïd et al (1994) showed that adding 1% monoglycerides reduced stickiness and caking of precooked couscous while increasing its firmness and resistance to overcooking.

Cooking also results in insolubilization of the wheat proteins. The gluten proteins quickly form large aggregates through the formation of disulfide covalent cross-links (Guezlane et al 1998b). These reactions could also contribute to a decrease in the sticky behavior of cooked couscous grains.

DRYING

The drying stage is necessary to obtain long shelf-life stability of the cooked couscous grains. Stability of dry couscous grains comes from reduction of water activity, by eliminating most of the water. The final moisture content of dry couscous grains should not be higher than 13.5%. Whereas the drying stage of pasta products has been widely studied, the drying of couscous grain has not really been considered in scientific study. A description of drying mechanisms and the molecular changes of the wheat components during couscous drying should thus be extrapolated by transposition of the available knowledge concerning drying of short-cut pasta products. Couscous grains can be considered easy to dry because their spherical shape and relative porosity are favorable to rapid water elimination. Couscous drying is conducted using a hot-air rotating dryer, which is similar to those used for drying short-cut pasta products. The dryer rotation causes a slight mixing of the product layer and generates close contact between the grains and the airflow (Quaglia 1988). Some “dust” is generated during the drying stage due to superficial erosion of grain under drier rotation. The dust particles are considered as fine recycled products and are reincorporated at the beginning of the production line (Fig. 10.4).

Couscous drying has been examined over a large range of drying temperatures and times, for example, 48 h at 25°C, 17 h at 55°C, 3 h at 95°C, and 30 min at 95°C (Guezlane et al 1998a, Ounane et al 2006). Drying conditions have not been demonstrated to influence the quality of the couscous grains. Guezlane (1993) reported that an increase in the drying temperature (from 55°C for 17 h to 95°C for 3 h) induced a reduction in swelling capacity of the couscous grains in cold water.

After the drying stage, the layer of hot product leaving the dryer is cooled to room temperature in a bed cooler, using a vibrating perforated frame cooler with cold air flow (Quaglia 1988).

FINAL SCREENING

The final stage of couscous processing is grading on sieves to select the different dry couscous grains according to size criteria (Quaglia 1988). The dry couscous grains are separated into coarse, medium (1–2 mm), and fine (0.6–1 mm) grades. They are stored inside silos and sent to the packaging area. Some out-of-scope products are generated during this screening stage (Fig. 10.4). The "very" coarse grains are ground in a two-stage roller mill and then sieved again. The excessively fine particles (<0.63 mm) are recycled at the head of the line, in the same way as dust collected from the dryer is. The fine particles go back to the production line and are used as "raw material" after dosing.

RECYCLING PROCESS

During couscous processing, the couscous grains are size-classified after both the rolling and the drying stages (Fig. 10.4). These operations generate flows of out-of-scope products (either too fine or too large), which must be recycled as raw material at the mixing stage. The flows of recycled particles can represent more than three times the flow of durum wheat semolina. The recycled particle flows represent economic constraints because of the high unnecessary energy expenses needed to treat them. The reincorporation of recycled particles requires significant technical know-how and must be taken into account in real time to ensure a stable process. The process presents technical challenges: to manage the recycled products when they are reincorporated into the raw materials (durum wheat semolina) and, more particularly, to define the wetting conditions required at the mixing stage to obtain an adequate agglomeration yield.

Two kinds of recyclings (with specific water contents and physicochemical states) must be considered during couscous processing. They are 1) recycled wet uncooked particles that are rejected after the rolling-calibrating stages and 2) recycled dry cooked particles that are recovered after the cooking and drying stages.

Recycled Wet Uncooked Products. These wet uncooked products are rejected after the mixing-rolling-calibrating stage and correspond to the wet agglomerates that are smaller or larger than the required size. They generate the main flow of recycled products during couscous processing. They can represent more than 2.5 times the initial flow rate of durum wheat semolina (Fig. 10.4). The main flow of recycled wet products comes from the too-small wet-recyclings fraction, which is about 10 times more important than the flow of the too-large wet recyclings. The extent of wet recycled products generated after the first screening stage mainly depends on the equipment used in the first stage of couscous processing, particle agglomeration by wetting and mixing. It is possible to obtain lower rates of recycled wet products by using a centrifugal wetting system and rest conveyor before the mixer (i.e., mechanisms based on coalescence) than by using the classical wetting-mixer equipment (i.e., mechanisms based on nucleation) (Hébrard 2002). The "out-of-scope" wet products are recycled directly (too small) or after a crushing stage (too large) at the entrance of the mixing stage and mixed with the initial durum wheat semolina (Fig. 10.4). The recycled wet products are then submitted to additional agglomeration mechanisms.

The biochemical composition of industrial recycled, wet, uncooked products is presented in Table 10.2. Compared to the initial durum wheat semolina, the recycled wet products are characterized by higher moisture content (31.6%), and similar starch (86%), protein (13.2–13.5%), and pentosan (1.7–1.8%) contents. When incorporated with the durum wheat semolina, the wet recycled products with high moisture content can be considered to be "preexistent" nuclei for the agglomeration mechanisms. However, their specific contribution during the formation of the agglomerates (in comparison with the contribution of the initial durum wheat semolina particles) is not fully understood.

Recycled Dried Cooked Particles. The flow of these products can represent about 10% of the initial flow rate of durum wheat semolina (Fig. 10.4). This flow is lower than those of the recycled wet products. A significant part of the recycled dried cooked particles cannot be reduced because they are the very fine particles (i.e., dust) generated inside the rotating drier by erosion mechanisms (Fig. 10.4). The out-of-scope dried cooked products are recycled directly (too small) or after a crushing stage (too large) at the entrance of the process and are mixed with the initial raw material (durum wheat semolina) (Fig. 10.4). The recycled wet products are then submitted to additional agglomeration.

The biochemical composition of the industrial recycled dried cooked products is presented in Table 10.2. Compared to the initial durum wheat semolina, the recycled dried products are characterized by low moisture content (8.7%), and similar starch (86%), protein (13.2–13.5%), and pentosan (1.7–1.8%) contents. But the recycled dry products are characterized by very high gelatinized starch content (75%) and very low soluble protein content (2.3%) compared to the initial durum wheat semolina (5.9 and 12.7%, respectively). The recycled dried products are also characterized by slightly higher values of mean particle size (d_{50} = 420 μm), particle size dispersion (1.4), and density (794 g/L) than the durum wheat semolina (260 μm, 0.9, and 670 g/L, respectively) (Fig. 10.7). The recycled dried products are then more heterogeneous in size and density. All of these changes are due to the thermal effects during steam cooking and drying, which bring about starch gelatinization and protein insolubilization.

TABLE 10.2
Comparison of Biochemical Composition and Physical Properties of Durum Wheat Semolina, Industrial Recycled Wet Products, and Industrial Recycled Dried Products

Parameter	Durum Wheat Semolina	Wet Recycled Products	Dry Recycled Products
Water content (g/100 g product)	14.5 (± 0.4)	31.6 (± 0.9)	8.7 (± 0.3)
Starch content (g/100 g dry matter)	86.2 (± 6.0)	85.8 (± 6.0)	85.6 (± 6.0)
Gelatinized starch content (g/100 g dry matter)	5.9 (± 0.3)	26.5 (± 1.3)	75 (± 3.8)
Total protein content (g/100 g dry matter)	13.5 (± 0.5)	13.2 (± 0.5)	13.3 (± 0.5)
Soluble protein content (g/100 g dry matter)	12.7 (± 0.6)	10.5 (± 0.5)	2.3 (± 0.1)
Total pentosan content (g/100 g dry matter)	1.7 (± 0.2)	1.8 (± 0.2)	1.7 (± 0.2)
Soluble pentosan content (g/100 g dry matter)	0.1 (± 0)	0.2 (± 0)	0
Free lipid (g/100 g dry matter)	1.4 (± 0.1)	…	0.7 (± 0.1)
d_{50} (μm)	300 (± 30)	560	295 (± 29)
$(d_{90} - d_{10})/d_{50}$	0.9	1.3	1.4
Density (g/L)	670	652	794

The biochemical differences observed for the recycled dried cooked products are responsible for the low couscous-making behavior of these products and, more particularly, to their poor agglomeration behavior during mixing and rolling. The recycled dried cooked particles are not able to agglomerate (Hébrard 2002). As a consequence, if their recycling flow is not well managed by adjusting the water addition level, an excess or a lack of agglomeration yield may occur. As a consequence, it is better not to directly incorporate the flow of recycled dried cooked products with the semolina in the mixer. The recycled dried cooked products must be first stored in a separate silo and mixed in a constant ratio with the native raw material so that the water addition level can then be more evenly adjusted.

The couscous industry faces a range of questions, including large recycle ratios, "poor" product quality control, and even the total failure of scale-up from laboratory to full-scale production. The great physical and chemical reactivity of durum wheat semolina particles constitutes a critical element for the management of the agglomeration processes. However, both scientific and technical descriptions of the wheat powder properties remain limited.

Even if our understanding of powder mechanics is greatly improved and sophisticated techniques to characterize formulations and grains are available both in the laboratory and in the plant for different particulate systems, there is still a lack of knowledge concerning the relationship between particle properties and the mechanisms at play in this process. The properties of the semolina particles (especially their surface properties) and the wetting-mixing process conditions could play a central role in the mechanisms involved in couscous production.

DURUM WHEAT PRODUCTS FROM BAKING

Durum Wheat Bread

Common wheat (*T. aestivum* subsp. *vulgare*) is commonly used to prepare leavened or flat bread. Durum wheat (*T. turgidum* subsp. *durum* Desf.) is the preferential raw material for pasta products because it gives a dough with superior rheological properties and pasta with optimum color and cooking quality. On the other hand, durum wheat is also utilized to produce different foods such as couscous, bulgur, and *frekeh* (staple foods in the Middle East and North Africa), breakfast cereal, and dessert. Finally, durum wheat flour has a long history of use for traditional kinds of bread, especially in southern Europe and in the Near and Middle East (Williams et al 1984, Williams 1985, Tessemma 1987, Quaglia 1988).

Durum wheat utilization in breadmaking was outlined by Quaglia (1988) in the first edition of this book. In some Middle Eastern countries, 70–90% of the durum wheat grown is used for making bread (Quaglia 1988), and in the Near East (Syria, Lebanon, and Jordan), 30 and 18% of the durum wheat is used to make two-layered and single-layered breads, respectively (Williams 1985). According to Palumbo et al (2000), more than 10% of the durum wheat harvested in Italy is destined for bread production. There has been an expansion of bread production from durum wheat in many other countries such as Canada, Russia, France, and Greece.

Two-layered bread, *khobz*, is the most popular bread in Syria, Lebanon, and Jordan. In Egypt, this type of bread is called *baladi* or *shami*. In these countries, the single-layered bread is quite popular as well. In Turkey, the flat bread obtained from durum wheat is called *tandir ekmegi*. Several kinds of durum bread, with different names according to shape, area of production, and type of breadmaking, are currently prepared in many countries and are predominantly produced with artisan methods.

PHYSICOCHEMICAL BASIS OF DURUM WHEAT BREAD

Bread made with durum wheat generally shows a small loaf volume and a yellowish color and has a peculiar taste and smell, a fine and uniform crumb structure, and a long shelf life compared to bread from common wheat (Liu et al 1996, Raffo et al 2002). Troncone and Auricchio (1991) also reported that durum bread has less toxicity to people with gluten intolerance. These characteristics are related to several physical and chemical properties of the milling products (semolina and flour) obtained from durum wheat grain such as flour particle size, damaged starch, water absorption, protein (and gluten) content, protein (and gluten) quality, dough stability, amylolytic activity, maltose content, and yellow pigments (carotene and lutein), as described by Quaglia (1988). In general, for the purposes of breadmaking, common wheat and durum wheat differ from each other in their gluten viscoelastic properties. Durum wheat has weaker and less extensible gluten than bread wheat and a higher yellow-pigment content. In general, a milling product from durum wheat with superior breadmaking quality exhibits a strong gluten, which produces an extensive viscoelastic matrix during dough formation and shows good physical handling properties, such as high resistance to extension and moderate extensibility. The breadmaking performance of durum wheat improves as the gluten becomes stronger; however, durum wheat tends to have tenacious gluten, which results in inextensible dough and small loaf volume due to reduced oven response (Quaglia 1988).

Early baking studies claimed that durum wheat is unsuitable for breadmaking (Jago and Jago 1921, Gerhard 1925, Wihlfahrt

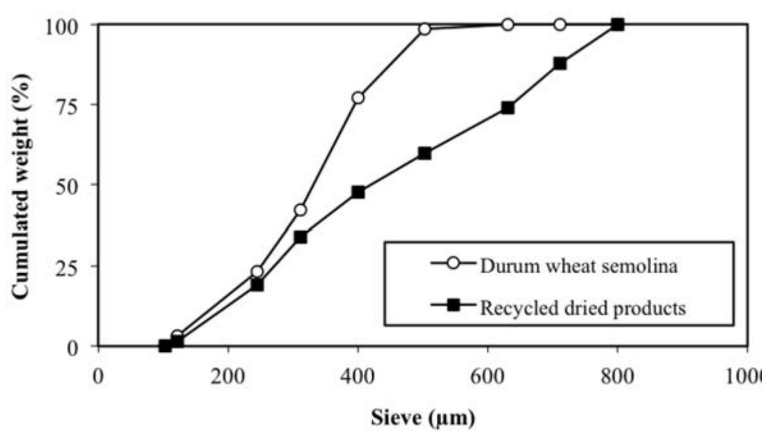

Fig. 10.7. Comparison of the particle size distribution between durum wheat semolina and the dry recycled particles.

1928). Nevertheless, Shepard (1903) showed that many people prefer bread made from durum wheat because of its palatable and nutritional qualities. Geddes (1932) also reported that bread made with durum wheat flour remained fresh for a longer period than bread prepared with common wheat. The long shelf life of durum bread is due to the high water-binding capacity of its flour (Saygin 1972, Boyacioglu and D'Appolonia 1994a, Raffo et al 2003).

On the other hand, several authors (Siebel and Stuhlmann 1924, Harris and Sibbitt 1950, Pavlov and Dekov 1973, Dekov et al 1986, Boggini and Pogna 1990, Lopez-Ahumada et al 1991, Boyacioglu and D'Appolonia 1994b, Sissons 2008) demonstrated that durum wheat flour can be used to improve the baking quality of common wheat flour and extend its shelf life by using either a sponge-dough (Hareland and Puhr 1999) or a straight-dough (Boggini et al 1997) breadmaking method.

The wider acceptance of durum breads spurred many researchers to study the breadmaking quality of durum wheat germplasm. Dexter et al (1981) demonstrated that some Canadian durum wheat cultivars approached acceptable baking characteristics, the use of semolina instead of flour resulting in improved dough-handling properties. Those authors concluded that there was no experimental evidence of any fundamental difference in the functional properties of gluten between durum wheat and common wheat. Quick and Crawford (1983) evaluated durum wheat cultivars with contrasting gluten quality for their breadmaking potential and showed that, compared to a hard red spring common wheat cultivar used as a reference, the strong-gluten durum wheat genotypes were equal in test weight, protein content, and dough-mixing pattern; superior in water absorption; and inferior in flour extraction and dough-handling characteristics. Josephides (1983) suggested that, among the factors affecting bread characteristics, the genotype (and particularly genes on chromosome 1B) had a major effect. Later, bread loaf volume was shown to be related to the gluten strength of the durum wheat cultivars analyzed (Josephides et al 1987). A high protein content generally provides superior baking performance, as does a short baking process. However, the "high-protein" durum wheat does not achieve the loaf characteristics obtained using common wheat flours (Dexter et al 1994).

The complex relationship between grain protein and breadmaking quality has been investigated by examining several factors such as protein content and composition (content of high molecular weight glutenin subunits [HMW-GS] and low molecular weight glutenin subunits [LMW-GS]), ratio of glutenin to gliadin, ratio of HMW-GS to LMW-GS, and unextractable polymeric protein (UPP) content. In general terms, glutenins are mainly responsible for dough elasticity, whereas gliadins strongly affect dough extensibility. As a consequence, the ratio of glutenin to gliadin can be directly related to the balance of dough strength and extensibility (Wrigley et al 2006), while the effect of variation in the ratio of HMW-GS to LMW-GS is less clear (Sissons 2008).

The breadmaking quality of Italian durum wheat cultivars was found to be associated with gluten viscoelastic properties, protein content, and protein composition. In particular, all cultivars with gliadin γ-42 were found to exhibit weaker gluten properties and lower loaf volume than those with allelic gliadin γ-45 (Boggini et al 1988, Spina et al 2003). Moreover, evidence has been provided that the composition of Italian durum wheat cultivars affects bread volume (Boggini and Pogna 1989). In particular, HMW-GS were found to affect gluten quality in the order "7+8" > "20" ≥ "6+8." Similar results were obtained by Payne and Lawrence (1983). This positive relationship between HMW glutenin composition and breadmaking quality was also confirmed by Pena et al (1994) in cultivars possessing HMW-GS 20, by Ammar et al (2000) in cultivars with HMW-GS 6+8, and by Edwards et al (2007) and Dexter (2008) in cultivars with both HMW-GS 7+8 and 6+8. These last two authors also demonstrated that subunit 20 caused weak gluten and inferior baking quality. The inferior gluten quality associated with HMW-GS 20 was noted by Carrillo et al (1990) as well. However, the use of alleles at the *Glu-B1* locus encoding for HMW-GS as markers of breadmaking quality in durum wheat is flawed by those contrasting results.

Liu et al (1996) showed that a link exists between gluten strength and LMW glutenin alleles. This confirmed early evidence that durum wheat genotypes possessing type-2 LMW-GS encoded by the *Glu-B3* locus on chromosome 1BS exhibit superior breadmaking quality (Boggini et al 1995). This positive effect was more evident in cultivars containing HMW-GS encoded by genes at the *Glu-A1* locus on chromosome 1AL, which are expressed in very few durum wheat cultivars (Dexter 2008).

According to Redaelli et al (1997), the reduced gluten extensibility of durum wheat as compared with bread wheat could be explained by the absence of prolamins encoded by chromosome 1D in durum wheat. Moreover, durum wheat has a small proportion of HMW-GS and a high proportion of LMW-GS compared with common wheat. This could have a negative impact on gluten quality because the amount of HMW-GS was shown to be correlated with glutenin polymer size, which in turn is positively correlated with gluten strength (Southan and MacRitchie 1999). In addition, the length of repeated sequences in LMW-GS is shorter than in HMW-GS (Sissons 2008).

However, as a general rule, the crust color of durum bread is dark because of the high levels of starch damage, total sugar content, and protein content. It is generally accepted that the major factors accounting for variation in breadmaking quality of common wheat cultivars are protein content and storage protein composition. Similarly, Dexter et al (1994) confirmed the importance of protein content on bread volume in durum wheat, as well as the significant impact of fermentation time on bread quality. Furthermore, Marchylo et al (2001) pointed out that a positive correlation exists between loaf volume and gluten strength in durum cultivars grown in Canada. Also Dexter (2008) demonstrated that the baking quality of Canadian durum wheat cultivars is positively associated with gluten strength and UPP content. However, the bread volumes of the Canadian durum genotypes with the strongest gluten characteristics were low (approximately 85%) compared with those of high-quality common wheat cultivars of similar protein content. Sapirstein et al (2007), showed that the dough strength and breadmaking quality of durum wheat are strongly correlated with the proportion of insoluble glutenin, which provides a measure of the amount of the highly polymeric glutenin fraction. Those authors also demonstrated the important role of fermentation time on loaf volume.

On the other hand, a strong correlation has been found between some alveograph parameters and the volume, softness, and shelf life of durum bread; low *P*/*L* ratios and moderate *W* values are associated with high bread volume and soft crumbs (Cubadda et al 1987, Pasqui et al 1991).

The milled products obtained from durum wheat grain affect breadmaking quality as well. In particular, semolina gives rise to bread with a spotted crust structure because of its large particle size, whereas flour yields breads with an external appearance similar to that of breads prepared from common wheat flour (Boyacioglu and D'Appolonia 1994a).

As a consequence of these findings, there is general agreement that a strong parallelism exists in the biochemical bases of breadmaking quality between common and durum wheat, baking performance and gluten strength being positively correlated in both wheat species. However, the bread volume of durum wheat is generally inferior to that of common wheat. In fact, the durum wheat cultivars analyzed so far show tenacious gluten properties, as revealed by their high tenacity (*P*) and low extensibility (*L*) alveograph values. This lack of dough extensibility is likely to the result of the absence of some critical protein components, particularly those encoded by homoeologus group 1 chromosomes. Obviously, chromosome-1D-encoded glutenin subunits are lacking in the tetraploid AB-genome of durum wheat. Therefore, several breeding programs have been activated in Canada, Italy, and the United States with the aim of improving the breadmaking quality of durum wheat by modification of its storage protein composition (Liu et al 1996, Palumbo et al 2000, Sapirstein et al 2007). A successful strategy for breeding durum wheat cultivars of superior breadmaking quality was based on crosses with tetraploid relatives (Sissons and Hare 2002). For instance, Kovacs et al (1998) increased grain protein content by crossing durum wheat with *T. dicoccoides*. Recently, Schlichting et al (2003) described some progeny lines with improved gluten extensibility and superior baking quality obtained from a cross between a strong, tenacious gluten durum wheat cultivar and a weak-gluten *T. turgidum* subsp. *diccoccum* accession.

A promising strategy to improve the baking quality of durum wheat is the incorporation of gluten proteins encoded by the D genome of common wheat into the *T. turgidum* spp. *durum* genome (Kaltsikes et al 1968). LMW glutenin subunits encoded by the *Glu-D3* locus on chromosome 1DS were found to have positive effects on breadmaking quality when introduced into durum wheat genotypes by chromosome engineering (Ceoloni et al 1996, Pogna et al 1996, Joppa et al 1998, Lafiandra et al 2000). Additionally, most of the novel tetraploid wheat lines obtained by interspecific breeding retained the pasta-cooking quality of their durum wheat parents, confirming earlier conclusions that dual-purpose durum wheat genotypes with superior pasta-making and breadmaking quality are feasible (Boggini et al 1996, Marchylo et al 2001).

REMILLED SEMOLINA

As mentioned above, the type of milled grain product (semolina or flour) and the baking protocols exert a significant influence on bread characteristics. In particular, the physical characteristics of the milling products should be carefully considered when choosing the most suitable breadmaking process. Durum wheat flour for breadmaking can be obtained either by remilling semolina (hence, the flour is called remilled semolina) or through direct milling. The remilling process reduces the particle size and, due to the extreme hardness of durum wheat kernels, can lead to excessive starch damage, which adversely affects the baking performance (Dexter et al 1994). However, Sarpirstein et al (2007) demonstrated that bread volume from remilled semolina is not influenced by the size of the particles in the milling product, assuming there is sufficient gassing power to sustain gas production throughout fermentation. Therefore, there should be no apparent advantage in regrinding semolina for baking.

Remilled semolina, commonly used in Italy, is obtained from semolina refined in a corrugated rolling-mill and has a fine particle size. In addition, it must comply with the Italian legal requirements (Italian law No. 580, 1967). The law requries maximum moisture of 4.50% and minimum of 1.35%, maximum ash of 1.60%, maximum cellulose of 1.0%, and minimum protein (N × 5.7) of 11.5%. All percentages are for dry matter. The paper bag of the remilled semolina must contain the wording "ONLY FOR BREADMAKING."

The high levels of protein content and starch damage of remilled semolina have the main effect of increasing the water absorption of the dough, thus leading to high bread yield; normally, 130–140 kg of bread is obtained from 100 kg of remilled semolina. Moreover, dough obtained from remilled semolina is characterized by high resistance to deformation, reduced extensibility, and high *P*/*L* ratios (Boyacioglu and D'Appolonia 1994a, Pogna et al 1996), which result in a modest volume development during leavening. The protein content and alveograph parameters of remilled semolina from leading durum wheat cultivars grown in Italy are reported in Table 10.3.

To be suitable for breadmaking, remilled semolina should have high protein content and farinograph stability and an alveograph *P*/*L* index of ≤1 (Boggini et al 1995, 1997). According to Quaglia (1988), to obtain a good-quality bread, the semolina or flour from durum wheat grain should have a particle size range of 120–190 µm, less than 7–7.5% starch damage, protein content >13% (dmb), and good gluten quality (alveograph *P*/*L* > 1.5 and *W* about 200 J × 10^{-4}).

TABLE 10.3
Rheological Parameters of the Remilled Semolina Obtained by the More-Diffuse Italian Varieties[a]

Varieties	Protein (N × 5.7)	Alveograph	
		W	*P*/*L*
Duilio	12.4	179	3.04
Creso	12.8	182	2.20
Ofanto	12.8	131	1.28
Grazia	12.8	184	1.31
Colosseo	12.3	177	1.04
Svevo	14.0	223	1.97

[a] Reprinted, with permission, from Raspatelli (2000).

Diverse Durum Breads

Fine semolina or durum flour can be used to prepare various kinds of bread, depending on the ingredients added and the dough-making, fermentation, and baking conditions. Western-style bread, similar to common wheat bread, is traditionally produced in southern Italy, Greece, and other Mediterranean areas. Whether or not fermented, the dough can be shaped into a thin disk and cooked on a plate (*tadjine*) or in an oven. If a flat bread, it is called Oriental type, of which there are many variations around the Mediterranean Basin (Williams et al 1988). The products obtained depend on the characteristics of the materials used, the water added, shaping conditions, and cooking temperatures (from 250° to more than 500°C). A detailed review of different types of flat breads has been published by Qarooni (1995). In this chapter, we consider more particularly the variety of bread products derived from durum wheat that may be encountered in Italy and North Africa.

ITALIAN BREAD

The most famous Italian durum wheat bread, made in the Apulia region and the only European bread awarded the "protected designation of origin" (PDO) label (EEC 2003), is the "*pane di Altamura*." This bread is produced with remilled semolina characterized by the above-mentioned rheological parameters (Raffo et al 2003, Pasqualone et al 2004). Furthermore, the protein quantity and quality of the remilled semolina from the durum wheat cvs. Appulo, Arcangelo, and Duilio e Simeto (i.e., the PDO-mandatory cultivars, which must be grown in the area of Altamura and make up at least 80% of the total semolina) were shown to affect the dough properties, hydration level during breadmaking, and water loss rate during bread storage, all phenomena having a strong influence on bread shelf life. The production protocol of *pane di Altamura* specifies all the breadmaking steps in detail. The official recipe, reported by Pagani et al (2006), is a sponge-dough breadmaking method, with 20 parts of full sourdough, 100 parts of remilled semolina, two parts of salt, and 60 parts of water. The full sourdough is prepared by adding ingredients at least three times (refreshment step). The final kneading takes 20 min, and the mass is then covered with a thick cloth to maintain a constant temperature and rested for 90 min. The final shape is obtained via three distinct molding phases, each coupled with a rest phase (intermediate proof) of established length. The baking operation must be performed under controlled conditions, in ovens heated with oak wood, in order to obtain bread loaves with a characteristic thick crust (at least 3 mm) and an atypical flavor, both due to the presence of remilled semolina and the sourdough process. The traditional shape of *pane di Altamura* is like a hat with a wide brim; it is also produced in the form of a large loaf, which can weight up to 2 kg (Fig. 10.8).

The main characteristic of this specialty bread, in addition to the typical yellow color of the crumb, is its long shelf life, reaching at least one week (Raffo et al 2002, 2003).

Another typical Italian durum wheat bread, named *carasau*, is the most important bread of the Sardinian tradition (Fig. 10.9). It is also known as "carta musica" (music paper) because of the particular sound it produces during chewing. *Carasau* is a round-shaped bread, about 40 cm in diameter and 2 mm thick, with no crumb, made of a blend of semolina and other by-products obtained from durum wheat milling. The very long shelf life of this bread is due to its low moisture content (about 6%), a consequence of the double cooking process. In the past, this long shelf life made *carasau* the most important food for shepherds, who lived away from the their family for up to five to six months without being able to acquire fresh bread (Bordo and Surrasca 2002).

This product is obtained from a straight-dough process in which semolina (100 kg), water (45 L), natural yeast (1 kg), and salt (2 kg) are mixed using a low-speed wishbone mixer; the resulting dough is used directly for breadmaking. Presently, industrial yeast is used for better standardization of the fermentation time. When the dough is ready, usually after a mixing time of a few min, it is divided, rested for about 60 min at 28–32°C, and sheeted by being passed through two rolling cylinders to obtain the traditional round shape. The layers of dough are put on cotton or flax sheets, piled up, covered, and rested for about 2 hr. Then they are baked at 560–580°C for a few seconds in an electric oven (or in a wood-burning oven, when homemade). The baked sheets, swollen by fermentation and high temperature, are taken out and cut through the middle to obtain two symmetrical

Fig. 10.8. *Altamura* bread.

Fig. 10.9. *Carasau* bread.

sheets that are baked and toasted for 15–20 sec at 400–410°C. The few existing studies on this breadmaking process emphasize that *carasau* bread needs semolina with intermediate protein content and a relatively high gluten index (Dettori et al 2002).

Durum wheat is used in Italy to produce many different types of bread, whose characteristics are reported in two books entitled *Atlante dei Prodotti Tipici: Il Pane*, edited by the Istituto Nazionale di Sociologia Rurale (1995), and *Atlante del Pane di Sicilia*, edited by the Consorzio Gian Petro Ballatore (2001). Some of these breads, such as *pane di matera* and *pagnotta del dittaino*, have "protected geographical indication" (PGI), which expresses the link between the product and its area of origin. However, this link is not absolute because it is not mandatory that all steps of the transformation process be performed in a particular geographical area. Nevertheless, PGI bread complies with strict regulations established for the production process. An inspection agency ensures compliance with the regulations. The sponge-dough breadmaking method is a common characteristic of all Italian durum breads, as well as those from other countries. This reduces the negative effects on loaf volume of both the extra-strong gluten properties and the low α-amylase activity of the milling products of durum wheat grain.

ORIENTAL BREAD

In North Africa, the general term used for bread is *kesra*. It includes all kinds of homemade bread. According to the components of the recipe (fat addition) and the baking diagrams (fermentation), five types of homemade bread are prepared and consumed around the Maghreb.

Matlouh. *Matlouh* (Fig. 10.10), one of the most consumed breads in the Maghreb, is prepared using these proportions: 100 g of semolina (medium and low particle size), 2 g of dry yeast, 2 g of salt, and 55–60 g of water according to the semolina quality. The salt is added to 4–5 kg of semolina in a wooden bowl and mixed manually. The yeast is diluted in half a glass of tepid water that is poured on the semolina. The water is added gradually while mixing until hydration is complete. The unrefined dough obtained is then manually kneaded for 30–35 min. This smooth and unsticky dough undergoes a bulk fermentation of about 40–70 min, according to the strength of the gluten (Cheriet and Namoune 2000). After fermentation, the dough is divided into equal segments of about 150–200 g. These pieces are shaped into balls with a wooden roller to give a flatten bread (girdlecake) with a thickness of 1 cm and a diameter of 25–30 cm. The dough is cooked on the surface of a warmed *tadjine* (a traditional terracotta plate with small, uneven spikes) for about 3 min. Then it is turned onto the second side, and holes are made with the tip of a knife or needle to allow gases to escape and to prevent blisters forming. The second side is cooked for 3 min. After both sides are cooked, the insufficiently cooked outside edges of this homemade bread are placed directly in the fire for a few seconds for a complete and homogeneous cooking.

After cooking, the bread has a thickness of 3 cm and a diameter of 25–30 cm. The crust is not crunchy but supple, and the crumb is soft with regular alveoli (pores). The specific density of the crumb is about 0.25 g/cm^3, slightly superior to that of some French loaves. The moisture content of the cooked product is about 35%. Loaf volume and regular alveolation of the crumb constitute the most important criteria of quality (Cheriet and Namoune 2000). This depends on the quality of the semolina and especially the gluten strength. The product is generally consumed the same day it is prepared and not beyond 24 hr, after which the product loses its aroma and freshness.

Maadjouna. This bread is made without yeast by mixing semolina of medium particle size with salt and water. As there is no proofing stage, the semolina gluten quality is not essential. After hydration and kneading, the dough is divided into balls of 200–300 g and then shaped into a circle from 25 to 30 cm in diameter and 0.5–0.6 cm in thickness. It is then baked on a warmed tadjine without any motives (smooth surface).

The bread (Fig. 10.11) has black blisters (from the Maillard reaction) on the two sides, with diameters of ≥1 cm. These blisters are similar to microbial colonies. The number of blisters can reach 10–15 for each side. However, Kezih et al (2001) observed that the top side of the homemade bread has fewer blisters than the bottom side. The crumb is compact and resistant to chewing and is not crisp. The crust is hard and relatively crunchy just after the cooking but is very sensitive to staling.

Rekhsis. This bread is also prepared without yeast (or with a very small amount) but by adding about 10 g of oil to 100 g of semolina (coarse and medium particle size) and 40–45 mL of water. The salt and yeast are added to 4–5 kg of semolina in a bowl, and the oil is added while mixing, followed by the water, which is added gradually to obtain a coarse dough. The mixture undergoes a rest period of about 10 min. The kneading time

Fig. 10.10. *Matlouh.*

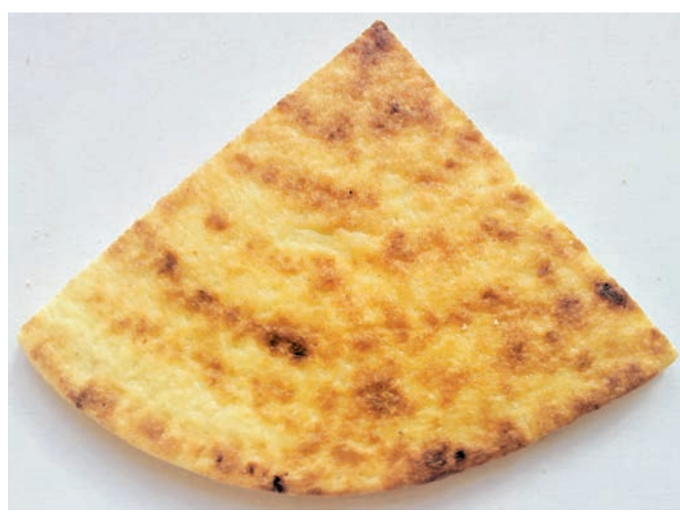

Fig. 10.11. *Maadjouna.*

is 15–20 min. The addition of fat facilitates the kneading of the dough, which becomes smooth and is not sticky. The dough is divided into pieces of 200–250 g, which are shaped into flatten bread 25–30 cm in diameter and 0.5 cm in thickness. The bread is cooked on both sides for 6–8 min. The product (Fig. 10.12) presents a brown-yellow (golden) color with a homogeneous surface without visible blisters because the added fat prevents this phenomenon. With a firm crust and a compact crumb, the product is crisp (brittle) after frying. It can be preserved for two to three days without staling.

***Mbesessa* or *harcha*.** This product (Fig. 10.13) is prepared from coarse semolina (100 g), oil or butter (20–25 mL), salt (2 g), and water (25 mL). Semolina is first mixed with salt and fat; then water is gradually added. A moderate kneading of 10 min contributes to forming a fragile, unrefined dough that has no viscoelastic properties and breaks easily (because it has no gluten network). This dough is divided into balls of 200–300 g, which are shaped into squares or diamond-shaped pieces of 8–10 cm and 0.6–0.7 cm thickness. The pieces of dough are then cooked on their two sides for 3–4 min. The end product is very crisp (brittle) with a homogeneous surface and a compact, easy-to-chew crumb. Because of its high fat content, the product is not predisposed to staling or to microbial contaminants, and consequently its shelf life is about one week. It is mostly consumed with butter or milk but not with soups, sauces (meats vegetables), or cheeses.

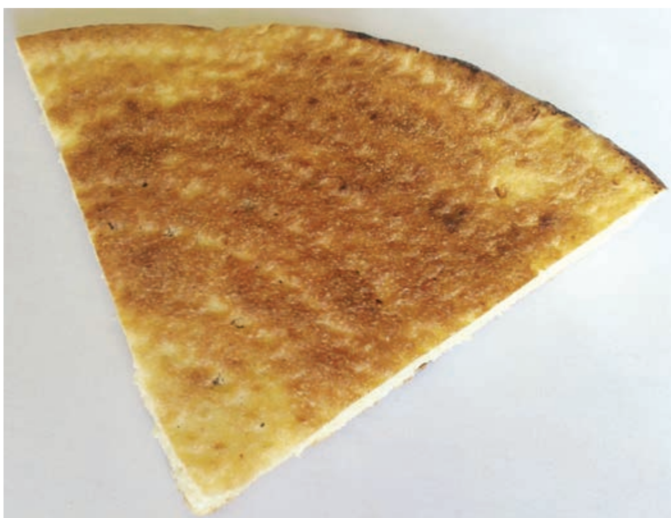

Fig. 10.12. *Rekhsis.*

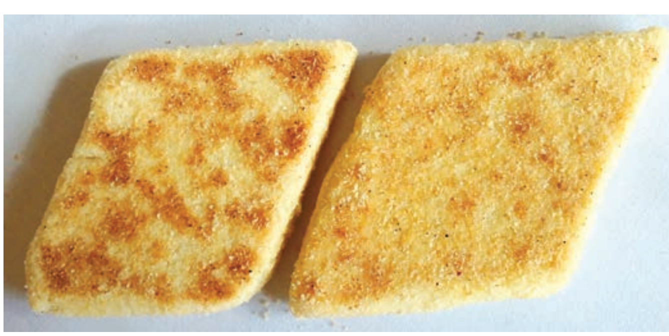

Fig. 10.13. *Mbesessa* or *harcha.*

Khobz-el-dar. The recipe for this bread is quite sophisticated. The ingredients are semolina of medium and small particle size (100 g), oil (20 mL), milk (10 mL), salt (2 g), yeast (2 g), one egg, sesame seeds (1 g), and water (20 g). The salt, sesame seeds, and yeast are diluted in tepid water and then added to 6 kg of semolina in a bowl. Afterward, the oil is incorporated during the mixing, and, finally, milk and water are added. After being mixed for 5 min, the resulting unrefined dough undergoes a rest period of 10 min. Then a kneading stage of 20 min results in a soft and smooth dough. The dough is divided in balls of 400–500 g and shaped into a round form of 35 cm diameter and 1.5–2 cm thickness. The fermentation stage lasts 1.5–2 hr. Before baking, the upper face of the bread is painted with egg yolk and a few sesame seeds. The bread is baked in metal trays on a single side in a bakery or kitchen oven for 20–25 min.

The bread (Fig. 10.14) has a final diameter of 35 cm and a thickness of 4–5 cm. The crust's upper face is slightly bulged out and has a golden, brilliant aspect. The crust texture is soft but crisp with brown sesame seeds. The crumb has a pronounced yellow color with regular alveolation. The crumb density is 0.35 g/cm^3, which is less of that of *matlouh* bread. Volume and texture of the crumb are the main quality criteria. The volume depends on the gluten quality of the semolina and also on the fermentation stage. The texture is a function of the proportions of oil, milk, and fat used. The product can be stored for a period of seven days without staling. It is consumed during ceremonies and family events and nowadays more and more as a replacement for French-type bread. Because of its popularity, this bread is now widely made and commercialized in bakeries. However, it is prepared from a mixture of semolina and common flour and with less fat, milk, and egg. These recipe changes obviously give a product with taste, texture, and color that are not comparable to those of genuine homemade bread. Moreover, such a product cannot be preserved beyond two days because of the loss of its freshness and its fast staling.

Durum Pastry

Durum semolina is widely used to produce specific pastry all around the Mediterranean Basin. In the Maghreb, these pastries are mostly associated with traditional events. Therefore, they are generally prepared with high sugar and fat contents. Under such conditions, semolina characteristics (e.g., gluten strength) are not crucial to the quality of the end products, which depend mostly on know-how.

Fig. 10.14. *Khobz-el-dar.*

PANCAKES

This type of pancake is prepared and consumed on the occasions of holidays, successes, or births. Several names are given to this type of product: *korsa* (Fig. 10.15), *ghraïf*, or *enjera* in Ethiopia (Steinkraus 1996), but these are distinguished from the *rghaïef* described by Dagher (1991).

The recipe consists of semolina or a blend of semolina with common wheat, salt, eggs, sugar, and dry yeast. According to Namoune et al (2003), semolina is first mixed with salt and sugar. Yeast is then added with some tepid water, and then eggs are introduced. The dough is formed by adding water and kneading for 10 min. After a short fermentation stage of 15 min near a source of heat, a second kneading is done with progressive addition of water until a liquid suspension results (moisture content of about 73%). This phase needs some know-how to avoid the forming of a gluten network (threads) and to obtain a homogeneous liquid suspension of semolina in water. The suspension undergoes a second fermentation stage of 45 min. With a ladle, an amount of this suspension is spread in a homogeneous way over the smooth *tadjine* and is cooked for 2–2.5 min on a single side. The size and regular distribution of pores on the upper side of the product constitute the most important criteria of quality.

SUGAR COUSCOUS

Some traditional products are prepared in the form of coarse couscous. *Rfiss* (Fig. 10.16), one of these products, is prepared with a mixture of several ingredients: semolina, oil, salt, butter, milk, water, water of orange flower, and powdered sugar. After the formation of unrefined dough, the product is spread in a tray with a determined diameter and depth and then cooked in an oven to give the product a brown tint. The cooked product undergoes crushing with a pestle and mortar to obtain fragments of a size comparable to that of coarse couscous. The crushed product is sieved to obtain a homogeneous particle size and undergoes a first steam cooking. Product aggregates resulting from cooking are then broken with addition of milk (10 g/100 g of semolina), water of orange flower (2%), and some butter (5%). The resulting product is mixed and rolled like couscous in a wooden bowl to give the grains a round shape and then is subjected to a second steam cooking. Finally, the aggregates of product are broken up, and 5% butter and 5% powder sugar are added.

The end product is not sticky and appears similar to coarse couscous. It has a yellow tint with a dark brown background and a sweet taste. It is consumed as meal especially on the occasion of holidays and ceremonies, especially the seventh day after weddings.

LAYER CAKES

Most of the these traditional products (*makroud*, *bradj*) are prepared from very specific raw materials: semolina, date paste, and water of orange flower. Other ingredients are fat, sugar, salt, and water. The preparation (Ouelhi et al 2004) consists of mixing the semolina (preferably of coarse particle size and with a low extraction rate) with salt and fat to obtain a homogeneous dough. After a rest period of 2–4 hr, moderate kneading with progressive addition of water is used to obtain unrefined or fragile dough. At the same time, the date paste is molded with the addition of oil and water of orange flower until a very soft and smooth paste is obtained. The date paste is placed within the semolina dough by preparing superimposed layers (*bradj*) or by filling through a hollow made in the semolina dough (*makroud*). The final shape is obtained by rolling, flattening, and cutting.

Products may be cooked on a *tadjine* but more generally are baked in bakery ovens. The product obtained (*makroud*) is shown in Figure 10.17. The top side of the product is a golden yellow with a crisp texture and a sweet taste. Because of their high content of fat and sugar, these products have a rather long shelf life (five to seven days) without risk of contamination or staling.

These products are quite high in caloric value. They are typically consumed at weddings, religious ceremonies, and other social occasions.

Fig. 10.15. *Korsa.*

Fig. 10.16. *Rfiss.*

Fig. 10.17. *Makroud.*

CONCLUSIONS

Cereal foods were probably not distributed randomly but have certainly answered specific needs. It seems quite obvious that the development of processing techniques was dependent on the availability of energy as well as the ability to use it. Accordingly, the diversity of products obtained from the same raw material, durum wheat, probably is a response to the existence of variable situations within the same geographical area—the Mediterranean area, where durum is typical—and suggests some adaptability to local limiting factors.

Besides this energy dependence, constraints arose mainly from characteristics of the raw materials involved. Thus, the primary processing of cereals derived directly from the morphological characteristics of grains, while the second-transformation processes are more dependent on the biochemical composition of the endosperm of cereals. Quite rightly, durum wheat grain has characteristics of texture and biochemical composition that allow very diverse uses. Its glassy texture allows it to lend itself fairly well to use as whole grains or cracked products. The semolina obtained after grain milling exhibits attractive agglomeration properties, allowing it to form couscous. In addition, durum wheat contains some proteins that allow wide diversity in foods comprising a wide variety of breads, biscuits, and pasta, which are associated with the Mediterranean diet.

This wide diversity of products and of associated processes has probably impacted the changing characteristics of durum wheat varieties grown in these regions. However, these specific properties (ease of use, the technofunctional properties, etc.) are probably not easy to characterize and to measure with the current laboratory methods, which are mainly dedicated to evaluation of pasta quality. A methodological effort should be undertaken to develop new analytical methods to assess the different end-use properties, to establish their physicochemical bases, and to determine the ability of durum wheat to be processed into these end-products. Such a phenotyping effort on durum wheat genetic resources would in turn give us comprehensive knowledge as well as a better understanding about the adaptability of durum wheat to different uses. In return, the genetic resources could be better exploited as a source of innovation for future uses of durum wheat.

REFERENCES

Abecassis, J., Bouniol, A., and Chaurand, M. 2005. Method for obtaining monocotyledon plant grains for human or animal food. European patent 052574.

Ammar, K., Kronstad, W. E., and Morris, C. F. 2000. Breadmaking quality of selected durum wheat genotypes and its relationship with high molecular weight glutenin subunits allelic variation and gluten protein polymeric composition. Cereal Chem. 77:230-236.

Bayram, M. 2005. Modelling of cooking of wheat to produce bulgur. J. Food Eng. 71:179-186.

Bayram, M. 2008. An analysis of scorched immature wheat: Frekeh. Cereal Foods World 53:134-138.

Bayram, M., and Öner, M. D. 2007. Bulgur milling using roller, double disc and vertical disc mills. J. Food Eng. 79:181-187.

Belaïd, M. R., Khendek, D., and Belarbi, A. 1994. Rôle des monoglycérides dans l'expression de la qualité du couscous de blé dur. Complexation amylose—Monoglycérides. Masters thesis, Institut National Agronomique El Harrach, Algeria.

Boggini, G., and Pogna N. E. 1989. The bread-making and storage protein composition of Italian durum wheat. J. Cereal Sci. 9:131-138.

Boggini, G., and Pogna, N. E. 1990. Utilizzazione del frumento duro come miglioratore della panificabilità del frumento tenero. Tec. Molit. 12:1025-1030.

Boggini, G., Palumbo, M., and Biancardi, A. M. 1988. Panificabilità delle varietà italiane di frumento duro. Tec. Molit. 7:609-617.

Boggini, G., Tusa, P., and Pogna, N. E. 1995. Bread making quality of durum wheat genotypes with some novel glutenin composition. J. Cereal Sci. 9:131-138.

Boggini, G., Tusa, P., and Galterio, G. 1996. Reliability of analytical parameters in evaluation of bread and pasta-making properties of durum wheat. Ital. J. Food Sci. 1:41-48.

Boggini, G., Pagani, M. A., and Luciasano, M. 1997. Qualità panificatoria di miscele di sfarinati di frumento duro con farine di frumento tenero. Tec. Molit. 48:781-791.

Bordo, V., and Surrasca, A. 2002. L'Italia del Pane. Guida Alla Scoperta e Alla Conoscenza. Slow Food Editore, Bra, Cuneo, Italy.

Boyacioglu, M. H., and D'Appolonia, B. 1994a. Characterization and utilization of durum wheat for breadmaking. I. Comparison of chemical, rheological, and baking properties between bread wheat flours and durum wheat flours. Cereal Chem. 71:21-28.

Boyacioglu, M. H., and D'Appolonia, B. 1994b. Characterization and utilization of durum wheat for breadmaking. II. Study of flour blends and various additives. Cereal Chem. 71:28-34.

Carrillo, J. M., Vasquez, J. F., and Orellana, J. 1990. Relationships between gluten strength and glutenin proteins in durum wheat cultivars. Plant Breed. 104:325-333.

Ceoloni, C., Biaggetti, M., Ciuffi, M., Forte, P., and Pasquini, M. 1996. Wheat chromosome engineering at the 4x level: The potential of different alien gene transfers into durum wheat. Euphytica 89:87-97.

Cheriet, G., and Namoune, H. 2000. Study of the home-made bread: Different types, recipes and making. Pages 24-26 in: Scientific Research Outlook in The Arab World and New Millenium: Science and Technology. University of Sharjah, United Arab Emirates.

Clarke, J. M. 1986. Effect of kernel water concentration at harvest and drying method on grades of red spring and durum wheats. Can. J. Plant Sci. 66:79-86.

Clarke, J. M. 1989. Loss of green colour and changes in kernel weight following windrowing of immature wheat. Can. J. Plant Sci. 69:721-727.

Consorzio Gian Petro Ballatore. 2001. Atlante del Pane di Sicilia. Grafiche Renna, Palermo.

Cubadda, R. E., Pasqui, L. A., Caproni, E., and Volpi, M. 1987. Qualitatseigenschalten von Brot aus Durumweizen. 1. Milleilung: Sortenunterscheide und bockverhalten. Getreide Mehl Brot 41:220-221.

Cuq, B., and Abecassis, J. 2006. Effects of semolina composition and processing conditions on couscous quality. (Abstr.) World Grains Summit: Foods and Beverages. (www.aaccnet.org/meetings/2006/abstracts/s-13.htm)

Czuchajowska, Z., and Pomeranz, Y. 1989. Changes in maturing wheat as determined by near-infrared reflectance spectroscopy. Cereal Chem. 66:432-435.

Dagher, M. S. 1991. Traditional foods in the Near East. Paper No. 50. Food and Nutrition Organization of the United Nations, Rome.

D'Appolonia, B. L., and MacArthur, L. A. 1976. Comparison of bran and endosperm pentosans in immature and mature wheat. Cereal Chem. 53:711-718.

Debbouz, A. 1992. Influence of raw material and processing on couscous quality. Ph.D. thesis, North Dakota State University, Fargo, ND.

Debbouz, A., and Donnelly B. J. 1996. Process effect on couscous quality. Cereal Chem. 73:668-671.

Debbouz, A., Dick, J. W., and Donnelly, B. J. 1994. Influence of raw material on couscous quality. Cereal Foods World 39:231-236.

D'Egidio, M. G., and Cecchini, C. 1998. Cariossidi di grano immature come alimento funzionale: Immature wheat grains as functional food. (In Italian) Tec. Molit. 49:1304-1310.

D'Egidio, M. G., Cecchini, C., Pagani, M. A., and Lucisano, M. 1996. Caratterizzazione chimico-fisica di cariossidi di grano duro immature: Physico-chemical characterisation of immature grains of durum wheat. (In Italian) Tec. Molit. 47:641-648.

Dekov, D., Zhelev, Z. G., and Lalev, T. 1986. Possibilities for using durum wheat in the improvement of bread from weak soft wheats. Cited in: FMBRA Abstract 91/00483. Flour Milling and Baking Research Association, Hertfordshire, England.

Dettori, M., Lendini, M., Mameli, L., and Musio, F. 2002. Durum wheat and traditional bread: Three years of experience with Carasau. Pages 263-275 in: Proc. 2nd Int. Workshop "Durum Wheat and Pasta Quality: Recent Achievements and New Trends." Istituto Sperimentale per la Cerealicoltura, Rome, Italy.

Dexter, J. E. 2008. The history of durum wheat breeding and summaries of recent research at the Canadian Grain Commission on factors associated with durum wheat processing. Presentation at Bosphorus 2008 International Cereal Conf. (http://www.grainscanada.gc.ca/research-recherche/dexter/hdwb-habd/hdwb-habd-eng.htm)

Dexter, J. E., Matsuo, R. R., Preston, K. R., and Kilborn, R. H. 1981. Comparison of gluten strength, mixing properties, baking quality and spaghetti quality of some Canadian durum wheat and common wheat. Can. Inst. Food Sci. Technol. J. 14:108-111.

Dexter, J. E., Preston, K. R., Martin, D., and Gander, E. J. 1994. The effect of protein content and starch damage on the physical dough properties and bread-making quality of Canadian durum wheat. J. Cereal Sci. 20:139-151.

Dick, J. W., and Matsuo, R. R. 1988. Durum wheat and pasta products. Pages 507-547 in: Wheat: Chemistry and Technology, 3rd ed., Vol. 2. Y. Pomeranz, Ed. Am. Assoc. Cereal Chem., St. Paul, MN.

Edwards, N. M., Preston, K. R., Paulley, F. G., Gianibelli, M. C., McCaig, T. M., Clarke, J. M., Ames, N. P., and Dexter J. E. 2007. Hearth bread baking quality of durum wheat varying in protein composition and physical dough properties. J. Sci. Food Agric. 87:2000-2011.

EEC (European Economic Community). 2003. Council Regulation No. 1291/2003 (PDO for Pane di Altamura). Off. J. EC No. 181, 19 July 2003.

Elias, E. M. 1995. Durum wheat products. Options Méditerranéennes. Série A, Séminaires Méditerranéens 22:23-31.

Geddes, N. F. 1932. Notes on durum wheat, the milling of semolina and manufacture of alimentary pasta. Confidential report. Associate Committee on Grain Research, National Research Council of Canada, Manitoba, Canada.

Gerhard, A. F. 1925. Handbook for Bakers. The Century Company, New York.

Grenet, C., Abecassis, J., and Feillet, P. 1993. Process for the preparation of parboiled wheat grains for human consumption. EU patent 5240728.

Guezlane, L. 1993. Mise au point de méthodes de caractérisation et etude des modifications physico-chimiques sous l'effet des traitements hydrothermiques en vue d'optimiser la qualité du couscous de blé dur. Ph.D. thesis, Institut National Agronomique, El Harrach, Algérie.

Guezlane, L., and Abecassis, J. 1991. Méthodes d'appréciation de la qualité culinaire du couscous de blé dur. Ind. Alim. Agric. 11:966-971.

Guezlane, L., Selselat-Attou, G., and Senator, A. 1986. Etude comparée du couscous de fabrication industrielle et artisanale. Ind. Céréales 43:25-29.

Guezlane, L., Colonna, P., and Abecassis, J. 1998a. Effet du traitement hydrothermiques du couscous de blé sur les modifications physiques de l'amidon. Anal. L'Inst. Natl. Agron. El Harrach 19(1-2):62-71.

Guezlane, L., Morel, M. H., and Abecassis, J. 1998b. Effet du traitement hydrothermiques du couscous de blé dur sur le comportement des protéines. Anal. L'Inst. Natl. Agron. El Harrach 19(1-2):72-81.

Hareland, G. A., and Puhr, D. P. 1999. Baking performance of durum and soft wheat flour in a sponge-dough breadmaking procedure. Cereal Chem. 75:830-835.

Harris, R. H., and Sibbitt, L. D. 1950. Effects on baking quality of blending durum wheat flour with bread wheat flour. Bakers Dig. 24(4):21.

Hayta, M. 2002. Bulgur quality as affected by drying methods. J. Food Sci. 67:2241-2244.

Hébrard, A. 2002. Granulation de semoules de blé dur. Ph.D. thesis. Ecole Nationale Supérieure Agronomique, Montpellier, France.

Hébrard, A., Oulahna, D., Samson, M. F., Galet, L., Morel, M. H., Abecassis, J., and Fages, J. 2003a. Etudes morphogranulométriques et structurales des semoules de blé dur en relation avec leurs propriétés d'hydratation et d'agglomération en couscous. Récents Prog. Génies Procédés 15:489-496.

Hébrard, A., Oulahna, D., Galet, L., Cuq, B., Abecassis, J., and Fages, J. 2003b. Hydration properties of durum wheat semolina: Influence of particle size and temperature. Powder Technol. 130:211-218.

Hillman, G. C. 1985. Traditional husbandry and processing of archaic cereals in recent times: The operations, products and equipment that might feature in Sumerian texts. Part II: The free threshing cereals. Bull. Sumerian Agric. 2:1-31.

Huebner, F. R., Kaczhowski, J., and Bietz, J. A. 1990. Quantitative variation of wheat proteins from grain at different stages of maturity and different spike locations. Cereal Chem. 67:464-470.

Humeid, M., and Al-Amary, M. 1986. A study on mechanization of frekeh production in Jordan. 2. Study of some nutrients and cooking time of frekeh produced mechanically at different maturity stages of wheat heads. Dirasat 13(8):73-86.

Humeid, M. A., Takruri, H. R., and Umari, M. A. H. 1990. Amino acid content of durum wheat protein at different maturity levels of the grains suitable for frekeh making. Dirasat 17B(3):54-61.

Istituto Nazionale di Sociologia Rurale. 1995. Atlante dei prodotti tipici: Il pane. Angeli, F. Editore, Milan, Italy.

Iveson, S. M., Litster, J. D., Hapgood, K., and Ennis, B. J. 2001. Nucleation, growth and breakage phenomena in wet granulation processes. Powder Technol. 117:3-39.

Jago, W., and Jago, C. W. 1921. The technology of bread-making. Bakers' Helper Company, Chicago, IL.

Jayas, D. S., Sokhansanj, S., and Bergh, D. 1988. Effect of maturity and harvest method on drying rate of wheat. Dry. Technol. 6:213-223.

Jenkins, D. J. A., Wolever, T. M. S., and Jenkins, A. L. 1986. Low glycemic response to traditionally processed wheat and rye products: Bulgur and pumpernickel bread. Am. J. Clin. Nutr. 43:516-520.

Joppa, L. R., Klindworth, D. L., and Hareland, G. A. 1998. Transfer of high molecular weight glutenins from spring wheat to durum wheat. Pages 257-260 in: Proc. 9th Int. Wheat Genetic Symp. Vol. 1. A. E. Slinkard, Ed. Univ. of Saskatchewan Extension Press, Saskatoon, Saskatchewan, Canada.

Josephides, C. M. 1983. Effect of chromosome 1B on quality and agronomic characteristics of durum wheat, *Triticum turgidum* var. *durum*. Ph.D. thesis, North Dakota State University, Fargo, ND.

Josephides, C. M., Joppa, L. R., and Youngs, V. L. 1987. The effect of chromosome 1B on gluten strength and other characteristics of durum wheat. Crop Sci. 27:212-216.

Kadakal, C., Ekinci, R., and Yapar, A. 2007. The effect of cooking and drying on the water soluble vitamins content of bulgur. Food Sci. Technol. Int. 13:349-354.

Kaltsikes, P. J., Evans, L. E., and Bushuk, W. 1968. Durum-type wheat with high bread-making quality. Science Magazine 159:211-213.

Kang, S., and Delwiche, S. R. 1999. Moisture diffusion modeling of wheat kernels during soaking. Trans. ASAE 42:1359-1365.

Karlsson, R., Olered, R., and Eliasson, A. C. 1983. Changes in starch granule size distribution and starch gelatinisation properties during development and maturation of wheat, barley and rye. Starch/Staerke 35:335-340.

Kaulp, S. M., and Walker, C. E. 1986. Couscous in North Africa. Cereal Foods World 31:179.

Kezih, R., Namoune, H., and Cheriet, G. 2001. Optimization of the manufacturing diagram of two types of flat home made bread. Fourth Agric. Conf. "Scientific Research for Safe Agricultural Production." Jerash Private University–Faculty of Agriculture and Science, Jerash, The Hashemite Kingdom of Jordan.

Koksel, H., Edney, M. J., and Oskaya, B. 1999. Barley bulgur: Effect of processing and cooking on chemical composition. J. Cereal. Sci. 29:185-190.

Kovacs, M. I. P., Howes, N. K., Clarke, J. M., and Leisle, D. 1998. Quality characteristics of durum wheat lines deriving high protein from *Triticum diccoides* (6B) substitution. J. Cereal Sci. 26:624-627.

Kratzer, A., 2007. Hydration, dough formation and structure development in durum wheat pasta processing. Ph.D. thesis, Swiss Federal Institute of Technology, Zurich.

Lafiandra, D., Margiotta, B., Colaprico, G., Masci, S., Roth, M. R., and MacRitchie, F. 2000. Introduction of the D-genome related high and low molecular glutenin subunits into durum wheat and their effect on technological properties. Pages 51-54 in: Gluten Protein 2000. Proc. 7th Int. Gluten Workshop. P. R. Shewry and A. S. Tatham, Eds. R. Soc. Chem., Cambridge, U.K.

Litster, J., and Ennis, B. 2004. The Science and Engineering of Granulation Processes. Kluwer Academic Publisher, Dordrecht, Netherlands.

Liu, C. Y., Shepherd, K. W., and Rathjen, A. J. 1996. Improvement of durum wheat pastamaking and breadmaking qualities. Cereal Chem. 73:155-166.

Lopez-Ahumada, G. A., Valdes-Encina, V. A., and Ramirez-Wong, B. 1991. The use of a mix of emulsifiers to improve the baking characteristics of blends of durum and bakers wheat flour. Cereal Foods World 36:701-702.

Marchylo, B. A., Dexter, J. E., Clarke, F. R., Clarke, J. M., and Preston, K. R. 2001. Relationships among bread-making quality, gluten strength, physical dough properties, and pasta cooking quality for some Canadian durum wheat genotypes. Can. J. Plant Sci. 81:611-620.

Méot, J. M. 2006. Couscous technology. Pages 61-77 in: Proc. Congrès Scientifique Int. "Santé and Environnement." Groupe Clextral, Firminy, France.

Merendino, N., D'Aquino, M., Molinari, R., De Gara, L., D'Egidio, M.-G., Paradiso, A., Cecchini, C., Corradini, C., and Tommassi, G. 2005. Chemical characterization and biological effects of immature durum wheats in rats. J. Cereal. Sci. 43:129-136.

Namoune, H., Kezih, R., Hamza, N., Derouiche, M., and Boukezzoula, F. 2003. Effect of semolina concentration, starch, eggs and cysteine on some characteristics of the Algerian traditional pancake. First Symp. Egypto-Syrian. Agriculture and Alimentation in the Arab World: Constraints and Future Perspectives, Shrajah, United Arab Emirates.

Ouelhi, G., Namoune, H., and Messad, N. 2004. The traditional cake (makroud) in the Constantine city. Fourth Sci. Conf. of Agricultural Sciences, Assiut, Egypt.

Ounane, G., Cuq, B., Abecassis, J., Yesli, A., and Ounane, S. M. 2006. Effects of physicochemical characteristics and lipid distribution in Algerian durum wheat semolinas on the technological quality of couscous. Cereal Chem. 83:377-384.

Ozboy, Ö., and Koksel, H. 2001. Dietary fiber content of bulgur as affected by wheat variety. Acta Aliment. 30:407-414.

Ozboy, O., and Koksel, H. 2002. An application of linear regression technique for predicting bulgur yield and quality of wheat cultivars. Nahrung 46:21-24.

Pagani, M. A., Lucisano, M., and Mariotti, M. 2006. Italian bakery. Pages 527-560 in: Bakery Products: Science and Technology. H. Corke, I. DeLeyn, W.-K. Nip, and N. Cross, Eds. Blackwell Publishing Ltd., Oxford, U.K.

Palumbo, M., Spina, A., and Boggini, G. 2000. Agronomic and bread-making characteristics of durum wheat genotypes deriving from interspecific hybridisation with bread wheat. Pages 515-518 in: Durum Wheat Improvement in the Mediterranean Region: New Challenges. C. Royo, N. M. Nachit, N. DiFonzo, and J. L. Araus, Eds. Options Mediterranéennes. Sér. A, No. 40. Int. Centre for Advanced Mediterranean Agronomic Studies (CIHEAM), Zaragoza, Spain.

Pasqualone, A., Caponio, F., and Simeone, R. 2004. Quality evaluation of re-milled durum wheat semolinas used for bread-making in Southern Italy. Eur. Food Res. Technol. 219:630-634.

Pasqui, L. A., Paoletti, F., Caproni, E., and Volpi, M. 1991. Proprietà funzionali del grano duro ai fini della panificazione. Tec. Molit. 1:1-7.

Pavlov, P., and Dekov, D. 1973. A study of the varieties of durum wheat (*Triticum durum* Desf.) as breeding resources. Pages 201-210 in: Proc. Symposium on Genetics and Breeding on Durum Wheat. G. T. S. Scarascia, Ed. University of Bari, Bari, Italy.

Payne, P. I., and Lawrence, G. J. 1983. Catalogue of alleles for the complex gene loci Glu-A1, Glu-B1 and Glu-D1 which code for the HMW subunits of glutenin in hexaploid wheat. Cereal Res. Commun. 11:29-35.

Pena, R. J., Zarco-Harnandez, J., Amaya-Celis, A., and Mujeeb-Kazi, A. 1994. Relationship between chromosome 1B-encoded glutenin subunit compositions and bread-making quality characteristics of some durum wheat (*Triticum turgidum*) cultivars. J. Cereal Sci. 19:243-249.

Pogna, N. E., Mazza, M., Redaelli, R., and Ng, P. K. W. 1996. Gluten quality and storage protein composition of durum wheat lines containing Glu-D1/Glu-D3 loci. Pages 18-22 in: Proc. 46th Australian Gluten Workshop. C. W. Wrigley, Ed. Royal Australian Chemical Institute, Melbourne.

Pons, M. N., Vivier, H., Belaroui, K., Bernard-Michel, B., Cordier, F., Oulhana, D., and Dodds, J. A. 1999. Particle morphology: From visualization to measurement. Powder Technol. 103:44-57.

Qarooni, J. 1995. Wheat usage in the Middle East and North Africa. Pages 215-249 in: Wheat End Uses Around the World. H. Faridi, Ed. Am. Assoc. Cereal Chem., St. Paul, MN.

Quaglia, G. B. 1988. Other durum wheat products. Pages 263-282 in: Durum Chemistry and Technology, 1st ed. G. Fabriani and C. Lintas, Eds. Am. Assoc. Cereal Chem., St. Paul, MN.

Quick, J. S., and Crawford, R. D. 1983. Bread baking potential of new durum wheat cultivars. Pages 851-856 in: Proc. 6th Int. Wheat Genetics Symp. S. Sakamoto, Ed. Plant Germplasm Institute, Kyoto, Japan.

Raffo, A., Bertone, A., Catone, T., Imperiali, A., Moneta, E., Nardo, N., and Quaglia, G. B. 2002. Caratteristiche nutrizionali ed organolettiche di pani tipici di grano duro. Tec. Molit. 53:799-808.

Raffo, A., Pasqualone, A., Sinesio, F., Paoletti, F., Quaglia, G. B., and Simeone, R. 2003. Influence of durum wheat cultivar on the sensory profile and staling rate of Altamura bread. Eur. Food Res. Technol. 218:49-55.

Raspatelli, V. 2000. I grani per il rimacinato: Il "caso Altamura." Molini Ital. 51(3):33-39.

Redaelli, R., Pogna, N. E., and Ng, P. K. W. 1997. Effects of prolamins encoded by chromosome 1B and 1D on the rheological properties of dough in near-isogenic lines of bread wheat. Cereal Chem. 74:102-107.

Sapirstein, H. D., David, P., Preston, K. R., and Dexter, J. E. 2007. Durum wheat breadmaking quality: Effect of gluten strength, protein composition, semolina particle size and fermentation time. J. Cereal Sci. 45:150-161.

Saygin, E. 1972. Studies on staling of bread wheat. Faculty of Agriculture Pub. No. 175. Ege University, Izmir, Turkey.

Schlichting, L. M., Dexter, J. E., Preston, K. R., Edwards, N. M., Marchylo, B. A., Hucl, P., and Perron, C. 2003. Quality characteristics of lines from a cross between emmer (*T. dicoccum*) and durum (*T. durum*) wheat. Pages 71-76 in: Proc. 2nd Int. Workshop on Durum Wheat and Pasta Quality: Recent Achievements and New Trends. M. G. D'Egidio, Ed. Ind. Grafica Failli Fausto, Guidonia, Italy.

Shepard, J. H. 1903. Macaroni wheat. Its milling and chemical characteristics. Bull. 82. S.D. Agric. Exp. Stn., Brookings, SD.

Siebel, P. F., and Stuhlmann, F. 1924. Siebel's Manual for Bakers and Millers, 2nd ed. Siebel Institute of Technology, Chicago.

Sing, S., Sharma, S., and Nagi, H. P. S. 2007. Effect of cooking treatments on the physical properties of bulgur. J. Food Eng. 44:310-314.

Sissons, M. J. 2008. Role of durum wheat composition on the quality of pasta and bread (Review). Food 2(2):75-90.

Sissons, M. J., and Hare, R. A. 2002. Tetraploid wheat—A resource for genetic improvement of durum wheat quality. Cereal Chem. 79:78-84.

Solah, V. A., Fenton, H., Kerr, D., Crosbie, G. B., and Siryani, S. 2007. Measurement of satiety of wheat-based bulgur by intervention and sensory evaluation. Cereal Foods World 52:15-19.

Southan, M., and MacRitchie, F. 1999. Molecular weight distribution of wheat proteins. Cereal Chem. 76:827-836.

Spina, A., Palumbo, M., and Boggini, G. 2003. Bread-making quality of new durum wheat cultivars. Pages 1394-1396 in: Proc. 10th Int. Wheat Genetic Symp. N. E. Pogna, M. Romanò, E. A. Pogna, and Galterio, G., Eds. Scalabrini Int. Migration Inst., Rome.

Steinkraus, K. H. 1996. Acid-fermented leavened bread and pancakes. Pages 149-211 in: Handbook of Indigenous Fermented Foods, 2nd ed. K. H. Steinkraus, Ed. Marcel Dekker, New York.

Stone, P. J., and Nicolas, M. E. 1996. Varietal differences in mature protein composition of wheat resulted from different rates of polymer accumulation during grain filling. Aust. J. Plant Physiol. 23:727-737.

Takruri, H. R., Humeid, M. A., and Umari, M. A. H. 1990. Protein quality of parched immature durum wheat (frekeh). J. Sci. Food Agric. 50:319-327.

Tessemma, T. 1987. Durum wheat breeding in Ethiopia. Pages 18-22 in: Fifth Regional Wheat Workshop for Eastern, Central, Southern Africa and the Indian Ocean. M. van Ginke and D. G. Tanner, Eds. Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT), Mexico City.

Troncone, R., and Auricchio, S. 1991. Gluten-sensitive enterophathy (celiac disease). Food Rev. Int. 7:205.

Turhan, M., and Gunasekaran, S. 2002. Kinetics of in situ and in vitro gelatinization of hard and soft wheat starches during cooking in water. J. Food Eng. 52(1):1-7.

Turhan, M., Gunasekaran, S., and Lamsal, B. P. 2001. Drying of gelatinized whole wheat. Dry. Technol. 19:333-342.

Umary, M. A., and Humeid, M. A. 1986. A study on mechanization of frekeh production in Jordan. 1. Parching and threshing mechanical equipment design. Dirasat 13(5):31-50.

Wall, J. S., and Carpenter, K. J. 1988. Variation in availability of niacin in grain products. Food Technol. 42(10):198-204.

Watanabe, M., Tokuyasu, K., and Sato, A. 1996. Analysis of the HMW glutenin subunits in immature seeds for selection of bread-making lines in wheat (*Triticum aestivum* L.). Breed. Sci. 46:103-105.

Wihlfahrt, J. E. 1928. A Treatise on Baking. The Fleischwan Company, New York.

Williams, P. C. 1985. Survey of wheat flours used in the Near East. Rachis 4:17-20.

Williams, P. C., and Jaby-El-Haramein, F. 1985. Frekeh making in Syria—A small but significant local industry. Rachis 4:25-27.

Williams, P. C., Srivastava, J. P., Nachit, M., and El-Haramein, F. J. 1984. Durum wheat-quality evaluation at ICARDA. Rachis 3:30-33.

Williams, P. C., El-Haramein, F. J., Nelson, W., and Srivastava, J. P. 1988. Evaluation of wheat quality for the baking of Syrian-type two layered flat breads. J. Cereal Sci. 7:195-207.

Wrigley, C., Bekes, F., and Bushuk, W. 2006. Gliadin and Glutenin: The Unique Balance of Wheat Quality. AACC International, St. Paul, MN.

Yettou, N., Aït Kaci, M., Guezlane, L., and Aït-Amar, H. 1997. Détermination des caractéristiques viscoélastiques du couscous cuit au moyen du viscoélastographe Chopin. Ind. Aliment. Agric. 12:844-847.

Yildirim, A., Bayram, M., and Öner, M. D. 2008. Ternary milling of bulgur with four rollers. J. Food Eng. 84:394-399.