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Pasta production

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6.1 Introduction

The basic forms of pasta products such as spaghetti, lasagna, macaroni, and other types of short goods, have not altered much over the centuries. Similarly, pasta continues to be made using the same ingredients: durum wheat semolina or flour, common wheat farina or flour, or various combinations of these, water and optional ingredients such as egg, spinach, tomato, herbs, etc. Modern processing technology, however, has changed dramatically. The large automated, computer controlled plants that we are familiar with today are very different from the small factories seen in the infancy of the modern pasta processing industry. Large amounts of pasta can now be processed in a day in modern plants that are run by only a few personnel.

Estimates of pasta consumption vary widely by country (Table 6.1). For example, Italy consumes the most at about 28.5 kg/person/year¹ and regionally it may range as high as 48 kg in Sicily (personal communication, Marina Solinas, Agnesi). Italian domestic pasta consumption is flat and a proportion of the production is aimed at the export market. On the other hand, consumption is growing in other countries around the world. For example, in the United States, pasta consumption rose from about 3 kg/person/year in 1965 to an estimated level of 9 kg in 1999. In Canada, consumption is expected to have increased to just over 7 kg/person/year by the year 2000.² In South America, Venezuela has the second highest consumption next to Italy. Other South American countries such as Brazil have a much smaller consumption, about 4 kg/person/year, but show large growth potential. There are many reasons for the popularity of pasta but the most important ones are as follows:

Table 6.1 Estimate of pasta consumption of several countries from around the world

Country	kg/person/year	Country	kg/person/year
Italy	28.2	Germany	5.3
Venezuela	12.7	Spain	4.6
Tunisia	11.7	Turkey	4.5
Peru	9.9	The Netherlands	4.4
Switzerland	9.6	Austria/Australia/Israel	4.0
United States	9.0	Costa Rica	3.5
Greece	8.8	Finland	3.2
Chile	8.2	Poland	3.0
France	7.3	United Kingdom	2.5
Argentina	6.8	Mexico	2.3
Portugal	6.5	Denmark/Libya	2.0
Canada	6.3	Japan	1.7
Brazil	6.1	Romania	1.3
Russia/Sweden	6.0	Egypt	1.2
Belgium/Luxembourg	5.4	Ireland	1.0

Source: Survey conducted by the Italian Pasta Association (Unione Industriali Pastai Italiani¹), 1999.

- Pasta has an excellent nutritional profile. It is a good source of complex carbohydrates and a moderate source of protein and some vitamins. For example, a two-ounce portion of dry pasta contains about 210 calories and is about 75 percent carbohydrate, 13 percent protein, and 1.5 percent fat.^{3,4} In North America, dietary guidelines published by the United States Department of Agriculture and by Health Canada show that grain-based products, which include pasta, should be a major part of a healthy diet.
- Pasta represents good consumer value and, as such, it sells well in both good and bad economic times.
- Dry packaged pasta is virtually non-perishable if stored appropriately.
- Pasta is easy to cook, has a wholesome taste, and an extensive variety of dishes can be prepared using the many different pasta shapes and sizes available.

6.2 History of pasta processing

Pasta products are ubiquitous in households, restaurants, and institutional settings around the world, but their origins are only conjecture. Etruscan art found in the tombs of Revieli in Cerveteri (about 30 km northwest of Rome, Italy), suggests that a type of pasta product was consumed in this part of the world as early as 600 BC. In Genoa, there is a record of a will dated 1279 in which a basket-full of macaroni was bequeathed.⁵ Obviously, pasta was dear to the hearts of Italians even at that early date, and Italy is generally considered the home of pasta.

Pasta processing in its earliest form was a very simple procedure performed by artisans or 'pastaio'.⁶ Flour and water were mixed and kneaded into

dumpling-like form. The process evolved with time and it was discovered that the dough could be sheeted, cut into strips and then dried in the sun. The resulting dried pasta was safe for storage and could be readily transported.⁵

The mechanization of pasta processing gained momentum during the industrial revolution. According to Agnesi⁷ wooden extrusion presses were designed in the early 1700s and into the early nineteenth century. At the turn of the present century, equipment consisting of mixers, kneaders or gramolas, hydraulic extrusion presses, and drying cabinets were built to increase efficiency and throughput. Pasta processing during this era was a batch manufacturing process, which by its nature was laborious and restricted productivity. In addition, the finished pasta was not as consistent as the product we eat today. Numerous pasta plants utilizing this process, however, sprang up between 1900 and the mid 1930s. In the United States, for example, the pasta industry flourished following World War I and throughout the 1930s and the Great Depression.⁶

The processing industry was revolutionized circa 1934 with the development of the continuous press. The Bühler Brothers from Switzerland were the first to incorporate an extrusion worm into a continuous press. Around the same time, Braibanti, an Italian company, introduced a press that used a worm drive in conjunction with pistons. Automatic dryers were then added to the continuous presses with Augusto Fava credited with manufacturing and installing the first continuous pasta dryer.⁸ The first continuous, automatic production line, which processed semolina into dried spaghetti or macaroni ready for packaging was designed and built by a Swiss firm in 1946.^{9,5} Other developments that have impacted on pasta processing technology include:

- Application of vacuum during mixing and extrusion lessened oxidation of pigments and minimized the loss of pasta color.
- The use of Teflon inserts in bronze dies provided smoother and more uniform products with better appearance.
- The introduction of higher drying temperatures beginning in the 1970s produced products with improved cooking quality and gave better bacterial control in egg products. Shorter drying times enabled equipment manufacturers to build more compact drying lines for a given capacity.
- Computerization of pasta factories further increased production efficiency and capacity, and provided more consistency in product quality.

With the acceptance of high temperature drying and computer control, the pasta industry made significant progress in a relatively short time in terms of production capacities, product diversity, and consistency in product quality. As with many other industries, the pasta industry is now global in nature. With globalization, however, has come fierce competition and it is becoming ever more important for processors to produce pasta products with quality that is consistent over time, within regions in a country, and even from country to country. Consumers generally are becoming more discriminating in their quality requirements, and less accepting of variability in product quality, especially for high-end or premium products.

6.3 Pasta-making process

Pasta manufacturers today produce many varieties of dried products with hundreds of shapes and sizes available. These products may be broadly classified as either short or long goods. Internationally, the most well-known long goods are spaghetti (of various diameters), fettuccini, and linguini. Elbow-shaped-macaroni is probably the most familiar short good, along with penne and the many types of shells. Stamping the forms such as bow ties from an extruded thin sheet of dough produces another familiar group of short goods, Bologna-type pasta.

In addition to dried pasta with or without egg, there are fresh, frozen and microwavable pastas, instant pastas, retortable pasta, etc., available to consumers.¹⁰ Each of these products has its own processing requirements, but this chapter will focus primarily on the fundamental aspects of production of basic short and long dried pasta.

Simple schematic diagrams of long and short pasta production lines are shown, for reference purposes, in Figs 6.1 and 6.2. This chapter is intended to give a general overview of pasta-making equipment and the basic elements of pasta manufacturing. The pasta manufacturing process for both long and short goods has been described in detail in publications by many authors.^{9,11–15}

All types of pasta are prepared using a few common elements. In each instance, a semolina or flour is mixed with water to form a stiff dough. The dough is then shaped, usually by extrusion through various shaped dies. For dried pasta the formed product is dried to between 12 percent to 13 percent moisture content.

The main ingredient of premium quality pasta is 100 percent durum wheat semolina. Semolina, which originates from the endosperm of durum wheat, is essentially coarse flour. Good quality pasta can also be made with durum wheat flour or a blend of semolina and durum wheat flour (granular). Pasta can be produced using common (soft or bread) wheat farina or flour, but is generally inferior in appearance (color) and cooking quality to pasta made from durum wheat.

In the first stage of the process, semolina and water are initially combined in a premixer (normal range 25–30 kg of water per 100 kg semolina¹⁵). The amount of semolina, water and other optional ingredients (such as eggs, enrichment, spinach, herbs, etc.) are measured and dispensed using various types of dosers depending on equipment manufacturer.¹⁴ If fresh eggs are added, the amount of water is adjusted accordingly. This mixture is then combined into a homogeneous mass in a mixing chamber. Water temperature should be controlled and water quality is a consideration. Semolina particles must be hydrated homogeneously during mixing to prevent the inclusion of white specks (unhydrated semolina particles) or streaks in the finished dried pasta. Small particles absorb water more rapidly than coarse particles, so semolina particle size distribution should be as narrow as possible to minimize uneven hydration. A Vortex vertical hydration system, recently marketed by

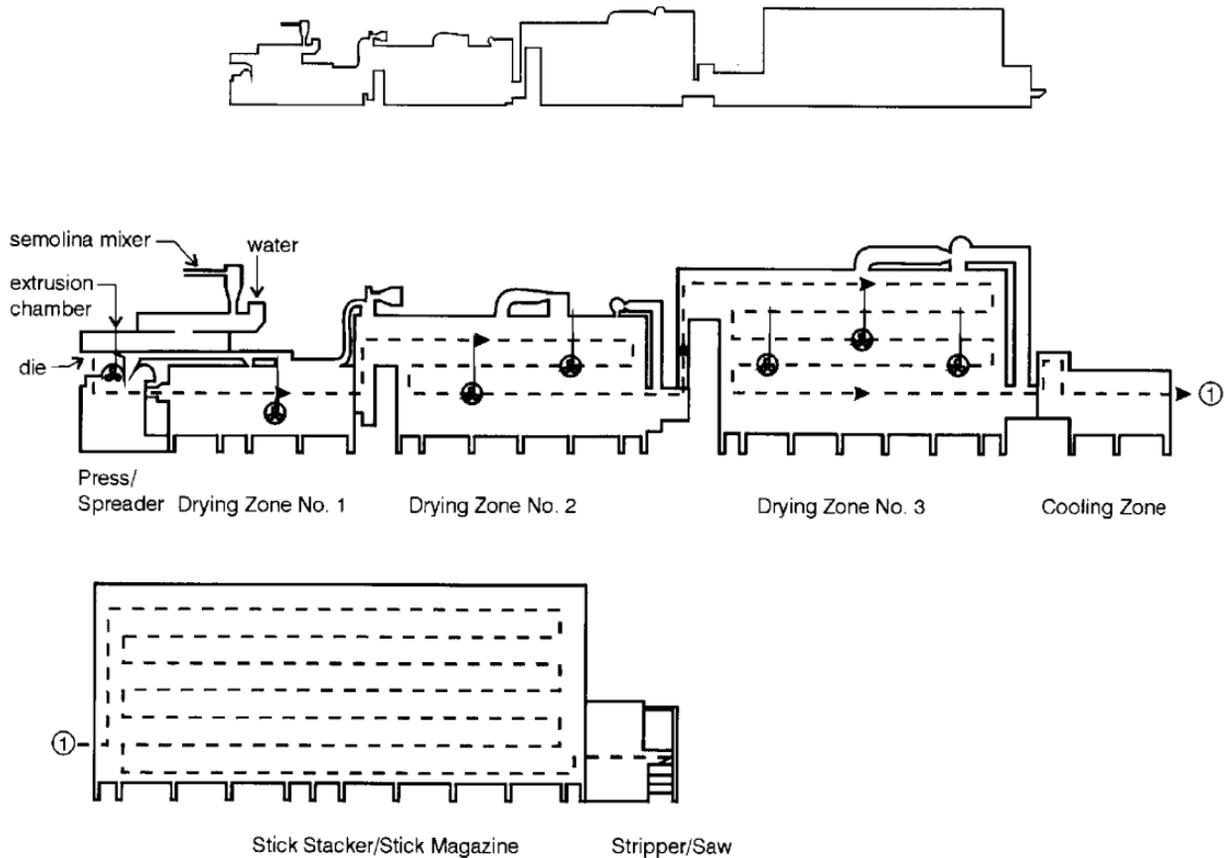


Fig. 6.1 A simple schematic of a long goods pasta line. (Adapted with kind permission from a diagram by Bühler AG, Uzwil, Switzerland.)

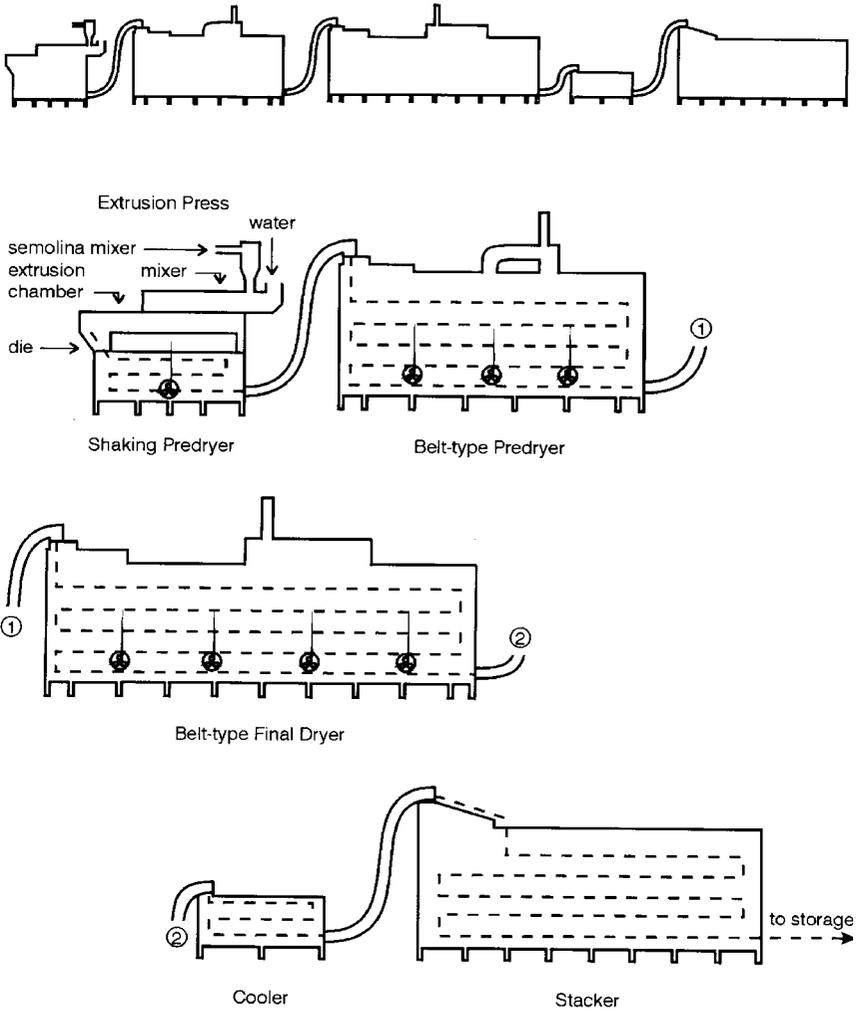


Fig. 6.2 A simple schematic of a short goods pasta line. (Adapted with kind permission from a diagram by Bühler AG, Uzwil, Switzerland.)

Braibanti, reportedly gives homogeneous hydration irrespective of granulation.

The product of a conventional pasta mixer is not a cohesive dough, but rather a mixture of agglomerated lumps of semolina.¹⁶ This mixture, through the action of mixing paddles or kneading blades, passes from the mixing chamber to the extrusion chamber and extrusion worm where the dough is formed and developed under pressures in the range of 80–120 kg/cm². Temperature, water absorption, and the rotational speed and geometry of the screw influence the magnitude of the pressure. Presses also have the facility to reintroduce scraps

from the spreader or cutter into the mixing trough. Ground dried waste (regrinds) are also used along with the semolina in short pasta lines. Care must be taken however, to ensure that final product quality is not decreased by the reintroduction of inordinately high levels of regrinds.¹⁴

Dough temperature during the extrusion process should not increase above about 50°C to prevent damage to the gluten network, and consequently to final product cooking quality. Heat, generated by the pressure and friction created during the extrusion process, must be dissipated through cooling to prevent inordinately high dough temperatures. To this end water, which is at a temperature of 20–30°C, is circulated in water jackets around the extrusion cylinder and head. Mixing and extrusion chambers operate under vacuum to minimize oxidation of the carotenoid or xanthophyll pigments. Oxidation of these pigments is known to decrease the yellow color of finished pasta. In addition, the vacuum prevents air bubble formation, which can give rise to defects and an unsightly appearance in the dried product.

In recent years engineering innovations have developed presses with much greater capacity and improved performance. For example, in 1995 Bühler introduced the Polymatik press that mixes and develops the dough in 20 seconds. This extrusion press is based on a twin-screw mixer/kneader system, and according to the manufacturer it provides good dough development with improved product color. In conjunction with a 'Clean in Place' (CIP) system, the manufacturer also reports that the Polymatik furnishes excellent sanitation. From a capacity perspective, presses with an 8000 to 10 000 kg/h capacity have been manufactured recently by different manufacturers.

The dough must now be shaped before it is dried. In the case of long goods, the dough is augered forward by the screws into the diffuser/spreader tube. The apparatus spreads the dough over the long straight die and the long good is then extruded into strands. The strands are spread evenly onto metal sticks, and automatically cut to the appropriate length. The product is immediately subjected to a blast of hot air to minimize strands sticking together before entering the pre-dryer. In the case of short goods the dies are circular and rotary cutters cut the product. The pieces fall onto a shaker/conveyor where they are also exposed to circulating hot air to set their shape and to prevent pieces sticking together. The moisture loss in this, the shaking pre-dryer, is up to about 5 percent.

The product must now be dried down to a moisture of around 12.5 percent to ensure that it is strong and will have a long storage life. The drying process itself must be managed carefully to attain a uniform rate of water removal. Otherwise, the outside surface of the product may dry too quickly and harden too much before the inside has dried. Formation of such a barrier will hinder natural moisture diffusion and set up undesirable stresses within the product. These result in 'checking', or fracture lines in the product, which may give rise to breakage of the product during packaging and handling. Such a result will impact negatively on consumer acceptance because of a poor appearance and inferior cooking quality. Thus, proper drying is perhaps the most critical stage in

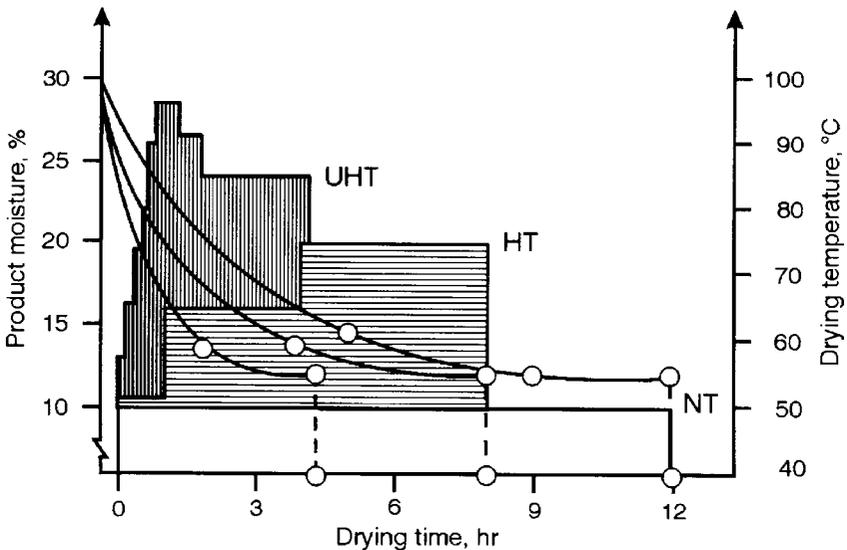


Fig. 6.3 Drying diagrams at ultra-high temperature (UHT), high temperature (HT) and normal temperature (NT) for the drying of long goods. (Adapted with kind permission from a diagram (c. mid-1990s) by Bühler AG, Uzwil, Switzerland.)

the production of high-quality pasta products that are acceptable to the demands of increasingly quality conscious consumers around the world.

As will be discussed in more detail later, there have been many innovations in drying technology in the latter part of the twentieth century. In general, moving the pasta through a number of drying zones maintained at precise temperature and relative humidity completes drying. Different equipment manufacturers have developed their own approach to the drying process, but in each case the general process is much the same. Drying of long goods (Fig. 6.3) is more delicate than that of short goods (Fig. 6.4). As a result greater care and longer drying time must be taken to reduce the moisture content of long goods.

For long goods, the first stage of drying is carried out in the pre-dryer where the moisture content is decreased from about 30 percent down to around 17 to 19 percent. In the case of short goods, the moisture content has already been lowered and decreases from about 25–27 percent down to between 17 to 19 percent. The pasta, long or short, then moves into the final drying phase where the moisture content is further reduced to about 12.5 percent. The product is then stabilized so that the moisture remaining within the product can redistribute itself evenly so that there are no stressful moisture gradients from the center to the outside of the product. If the product is not provided with appropriate stabilization, stress fractures or checking may develop. In the case of long goods a dampening step may follow stabilization to slightly increase moisture content and further stabilize the product and thus protect it from cracking.¹⁷ The product must then be cooled to a temperature (28–32°C) close to that of the surrounding

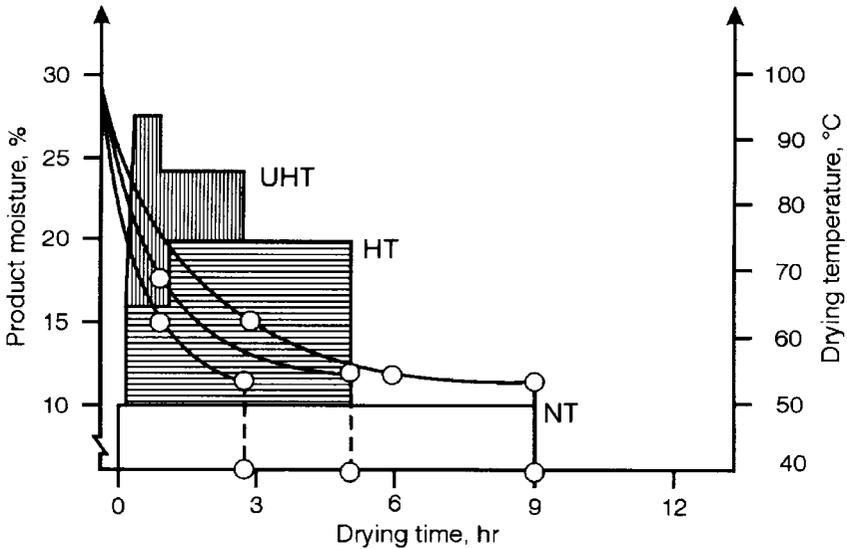


Fig. 6.4 Drying diagrams at ultra-high temperature (UHT), high temperature (HT) and normal temperature (NT) for the drying of short goods. (Adapted with kind permission from a diagram (c. mid-1990s) by Bühler AG, Uzwil, Switzerland.)

environment with a final moisture close to 12.5 percent. As noted above, long pasta moves through the drier zones draped over metal sticks. Short goods are generally conveyed through the dryers on belts. Dryers may contain multiple levels of belts or sticks.

Cooled short goods are conveyed into bins in preparation for packaging. In the case of long goods, following cooling the product passes through the stick stacker where the product is removed from the sticks, and onto the stripper-saw that then cuts the pasta with high-speed saws. This operation removes the bends (the portion of the strand which curves over the stick) and trims the product to the appropriate length for packaging.

Packaging is a most important process since it protects the product from breakage or contamination before delivery and sale. In the case of product destined for sale on the store shelf, it must also present the product in an attractive manner to appeal to the consumer. More recently, with the advent of stringent labeling laws in many countries, the package itself is a necessary means of providing among other things important nutritional information to the consumer.

6.4 Advances in drying technology

The drying of pasta, as described above, has seen numerous innovations over the past 25 years or so. Undoubtedly, the most important advances in pasta

processing have taken place in drying technologies.^{8,12} Drying diagrams typical of LT/HT/UHT for short and long pasta are illustrated in Figs 6.3 and 6.4.

Before the 1970s drying was performed at relatively low temperatures (LT) up to a maximum of 60°C, and drying times for long goods were 18 h or more. Low temperature drying processes are now considered the traditional means of drying.¹⁸ High temperature (HT) drying at temperatures of 60–85°C was introduced to the industry in the 1970s and early 1980s.^{19,20} The initial driving force behind the development of HT drying was improved bacterial control for egg products. Another immediately recognized benefit was much shorter drying cycles (≈8 h) that permitted more compact drying lines for a given capacity concomitant with a reduction in the high capital costs associated with plant space. As HT drying cycles became operational, it was discovered that an additional benefit was improved cooking quality and better color.^{20–22} Once the benefits of HT drying to product quality became generally recognized, HT quickly became the process of choice for most pasta manufacturers worldwide.

In the past few years, the application of ultra-high temperature (UHT) drying (85–110°C) has become common, with drying times as short as ≈4–5 h for long goods and ≈2–3 h for short goods. UHT drying reportedly produces pasta products with cooking quality and color equal to or better than that obtained with HT drying.

The impact of drying temperature on pasta cooking quality is readily apparent from a recent study by Schlichting *et al.*²³ (unpublished results). As seen in Table 6.2, when six Canadian durum wheat varieties of comparable protein content were processed into spaghetti at four drying temperatures, they all exhibited a similar response. As drying temperature increased, cooked spaghetti peak firmness increased.

In essence, the introduction of HT and UHT drying technology has enabled the pasta industry to produce pasta products with acceptable or even superior cooking quality, using lower-grade raw material. This technology has also led to improvements in cooking quality of pasta made from common wheat farina or mixtures of durum semolina and farina.^{14,22} When HT drying is used the

Table 6.2 Cooked spaghetti firmness of Canadian durum wheat varieties dried at four drying temperatures²³

Drying temperature (°C)	Cooked Spaghetti Peak Force (g) ^a			
	40	70	90	95
Variety				
Kyle	878 a	869 b	965 b	1027 c
AC Avonlea	976 a	1033 a	1073 a	1219 a
AC Morse	875 a	928 ab	1009 ab	1121 bc
AC Melita	903 a	955 ab	1015 ab	1125 ab
AC Pathfinder	935 a	974 ab	1029 a	1117 bc
AC Navigator	964 a	972 ab	1061 a	1147 ab

^a Means in a column followed by the same letter are not significantly different ($P = 0.05$).

cooking quality, particularly surface stickiness of pasta made from 100 percent common wheat farina, or mixtures of durum semolina and farina, improve dramatically.²⁴

The improvement in color attributable to HT and UHT drying is a more intense yellow. For example, as shown by Schlichting *et al.*²³ (unpublished results) as drying temperature increased, Canadian durum wheat cultivars exhibited an increasing Minolta b*, indicative of greater yellowness, for most but not all varieties (Table 6.3). The improvement in pasta yellowness with increasing drying temperature has been attributed to inactivation of lipoxygenase, a bleaching enzyme linked to the loss of yellow pigment during pasta processing.²⁵

Of some concern with higher temperature drying, particularly UHT drying, is the potential for development of a brown or reddish color due to excessive non-enzymatic browning, i.e. the Maillard reaction, or the 'burning' of the pasta. A brown or red hue in pasta is detrimental to consumer acceptance in many countries where a bright amber color is preferred. The interaction between drying temperature and a brown or reddish hue is a complex one. As shown by Schlichting *et al.*²³ (unpublished results), Canadian durum wheat varieties exhibit variable tendencies to redness (Minolta a*) as drying temperature increased (Table 6.3). Also, the response to temperature is not linear, and becomes increasingly apparent as the temperature increases above 70°C. Factors associated with pasta color, including the interrelationships between varieties, growing environment, drying procedure and semolina extraction rate, are not well understood.²⁶

In addition to imparting a detrimental effect on pasta appearance non-enzymatic browning by the Maillard reaction, which involves the condensation of sugars with amino acids, particularly with the essential amino acid lysine, can have a negative impact on protein nutritional quality. Research has shown that under some HT and UHT drying conditions there is a loss of lysine, vitamins, and the formation of furosine.²⁷ The maximum temperature, duration of HT or UHT, and the moisture content of the product when HT or UHT is applied affect the extent of nutritional loss. Pasta equipment manufacturers in the development of commercial drying cycles have taken the nutritional implications of HT and UHT drying into consideration, but some nutritional loss is unavoidable. However, according to Pollini²⁸ the loss of nutritional value due to HT and UHT should not be considered a serious defect because generally pasta products are not consumed as a source of essential amino acids or B vitamins.

Regardless, HT and UHT drying have revolutionized the pasta processing industry. The reduction in plant space for a given capacity paved the way for the development of pasta lines with far greater capacity than would ever be possible with LT drying. Improvements in pasta color and pasta cooking quality have made the quality of premium pasta products available to the most demanding consumers better than ever before. The technology has allowed pasta manufacturers targeting less demanding consumers to use less costly raw material, thereby giving access to good quality pasta at an affordable price.

Table 6.3 Impact of four drying temperatures on color of spaghetti from Canadian durum wheat cultivars²³

Drying temperature (°C)	a* (redness) ^a				b* (yellowness) ^a			
	40	70	90	95	40	70	90	95
Variety								
Kyle	62.8 c	65.8 c	68.1 bc	67.9 bc	-0.10 b	0.21 b	3.37 b	5.00 b
AC Avonlea	64.2 bc	67.1 bc	68.2 bc	68.5 b	-0.57 c	-0.26 b	2.48 bc	4.09 c
AC Morse	60.6 cd	63.0 d	65.7 cd	65.0 cd	-0.13 b	-0.28 b	2.87 bc	4.19 bc
AC Melita	66.4 b	68.4 b	70.2 b	69.6 b	-0.64 c	-0.33 b	2.86 bc	3.09 d
AC Pathfinder	59.1 d	61.8 d	64.7 d	64.7 d	-0.73 c	-0.26 b	2.20c	2.90 d
AC Navigator	74.0 a	72.4 a	74.0 a	73.8 a	1.04 a	1.26 a	4.45 a	5.90 a

^a Means in a column followed by the same letter are not significantly different ($P = 0.05$).

6.5 Raw material selection

Globalization and increased competition within the pasta industry are pushing pasta processors to produce products that have consistent quality over time, among regions in a country, and even from country to country. Consumers are becoming more discriminating in their quality requirements and less accepting of variability in product quality. To achieve a quality final product processors must begin by using raw materials that have the desired quality characteristics. Another essential part of the raw material quality package, which includes both the durum wheat and its milled product, semolina, is uniformity and consistency.

The production of good quality pasta begins with the milling of good quality durum wheat. Many pasta manufacturing plants are integrated milling and pasta processing units. Durum wheat is purchased on the basis of specifications that ensure that the semolina will achieve the expected pasta quality. Independent durum wheat millers must also establish durum wheat quality specifications in response to customer specifications for semolina.

For durum wheat milling, the primary quality selection criteria that must be considered are related to the physical condition of the wheat. These characteristics are largely influenced by environmental conditions during the growing season and during harvest.^{29,30} The yield of semolina declines as kernels become thinner because the proportion of endosperm concomitantly decreases. The plumpness of kernels is related to weight per unit volume, or test weight. Therefore, minimum test weight is a widely used specification to ensure good milling performance.

Physical defects associated with surface discoloration of kernels are important because bright speck-free semolina is required to give the aesthetic appearance required for successful marketing of premium pasta products. The most common surface discolorations, black point (discoloration of the germ), smudge (more progressed infection extending into the crease) and mildew, are caused by fungi. Another fungal infection, *Fusarium*, reduces semolina yield due to kernel shriveling, and imparts inferior color to pasta. *Fusarium* is also a food safety concern because of associated mycotoxins such as deoxynivalenol (vomitoxin).

Weather damage can also impart serious physical defects. Frost prior to kernels reaching physiological maturity causes shriveled kernels, which impact on semolina yield. Immaturity associated with frost damage causes greenness, which in turn impacts negatively on pasta color. Pre-harvest sprouting due to damp harvest conditions results in high levels of the starch degrading enzyme α -amylase. The most accepted test to estimate α -amylase activity is Falling Number (FN), which estimates the thickness of a hot wheat-water slurry by measuring the time in seconds for a plunger to free-fall through the paste. Many manufacturers of premium pasta specify very high FN because they believe that starch degradation due to α -amylase will cause greater loss of solids during cooking, increased surface stickiness and softer cooked pasta texture. However, there is no firm scientific evidence that α -amylase has an adverse effect on pasta cooking quality unless sprout damage is very severe.³¹

A minimum hard vitreous kernel (HVK) content is an important trading specification because of its relationship to milling quality and protein content. Kernels, which are not vitreous (commonly referred to as starchy or mealy kernels, or yellow berry because of their opaque yellow appearance), are softer than vitreous kernels, and, in general, as HVK declines the yield of coarse semolina declines, negatively affecting milling quality. This aspect of HVK may become less important in the future as high-speed mixing technologies and improved extrusion press technologies come into more general use. Pasta equipment manufacturers are recommending finer semolina particle size for manufacturers using these technologies, making the greater production of flour and fine semolina during milling associated with lower HVK of less concern.

The next group of quality selection criteria to consider are related to various components found in the wheat and semolina. Of these, protein content is the most important of all durum wheat and semolina quality characteristics since it has a major influence on cooking quality.³²⁻³⁴ HVK specifications have traditionally been used to guarantee sufficient protein content to achieve the desired pasta texture. With the development of rapid instrumental protein testing (near infrared technology) protein content guarantees are becoming an accepted part of durum wheat sales agreements, which makes the use of an HVK specification as a protein guarantee redundant.

High protein durum wheat of good physical condition is highly desirable because it will generally yield a semolina of uniform particle size with a minimum number of starchy semolina particles, and thus will hydrate evenly during mixing and will produce a pasta product which is physically strong and elastic. Such a pasta product will swell adequately during cooking, will not leave much residue in the cooking water, and will remain firm when kept in warm water after cooking and before it is served. Generally, as protein content increases, the cooked pasta becomes firmer and less sticky, which are desirable characteristics to the consumer. Excluding raw material cost, durum wheat protein requirements in the pasta industry will vary, depending upon processing systems, manufacturers' quality philosophy, consumer demands, product line, raw material availability, blending capabilities (with common wheat or wheat of differing origins), etc. In general, however, a minimum protein content for durum wheat destined for pasta manufacturing is about 14 to 15 percent dry matter basis. Due to loss of protein during the milling process, the corresponding semolina protein content would be 13 to 14 percent dry matter basis.

Another closely-related selection criterion is the gluten strength or protein quality of a durum sample. Strong gluten is universally acknowledged as an important prerequisite for good pasta-making quality. Compared to weak gluten varieties of comparable protein content, strong gluten varieties exhibit less sticky dough with better extrusion properties and superior cooked spaghetti textural characteristics. There are a number of factors associated with cooking quality including bite, chewiness, stickiness, and resistance to overcooking, appearance, flavor and residue in the cooking water. Scientific evidence obtained so far indicates that the continuity and strength of the protein network

is directly related to the textural characteristics of the cooked spaghetti. These characteristics are influenced by the total protein content since as protein content increases so does the extent of the network. Protein quality is believed to affect the properties of the protein network. It has been shown that certain gluten proteins, in particular some low molecular weight glutenin subunits, play a direct role in the formation of the gluten network.^{35,36} Some of these subunits are more effective than others in forming a good network and influence the plasticity and elasticity of the resultant dough, and the extent of the protein network around starch granules.

A number of tests are used to determine gluten strength. For example, a simple wheat test is the sodium dodecyl sulfate sedimentation test (SDS).³⁷ SDS measures the volume of sediment from a suspension of ground wheat or semolina after a specified time, strong gluten being associated with higher volume. Minimum semolina SDS sedimentation values are imposed by some pasta manufacturers on semolina millers. The gluten index method^{38,39} is another test that is commonly used to determine gluten strength. The gluten index is the measure of the proportion of wet gluten that resists passing through a screen during centrifugation. Stronger gluten is associated with more retention of gluten on the screen. Thus, as the gluten index increases, on a scale of 0 to 100 percent, the gluten strength increases. A durum sample with a gluten index of around 40 percent is typical of the strength associated with conventional Canadian and American (North Dakota) durum wheat. Some markets also like to include some durum wheat with very strong gluten characteristics primarily for blending purposes.⁴⁰ The gluten index values of these durum varieties can be in the order of 90 percent or slightly higher. Such strength is typical of some European varieties, recently developed extra-strong varieties from Canada (such as AC Pathfinder as shown in Fig. 6.5), and American desert durum varieties (from southwestern United States).

Physical dough tests such as the Farinograph, Mixograph and Alveograph are also used in various parts of the world to give an indication of dough mixing characteristics. Figure 6.5 shows some Canadian varieties with physical dough properties characteristic of conventional strength (Plenty, Kyle), medium strength (AC Morse), and extra-strong strength (AC Pathfinder). The mixograph is used widely in the United States, but the Alveograph appears to be gaining favor internationally. Parameters derived from the Alveograph (P, pressure, related to the height of the curve; L, the length, P/L, the ratio of height to length and W, work, related to the area of the curve) are used by some companies for selection purposes.

The influence of drying technology on pasta properties has brought some of the traditional criteria for durum wheat selection related to protein content and gluten strength into question. For example, there is evidence that under HT and UHT drying conditions protein strength has less influence on pasta cooking quality than under LT drying conditions.³⁴ Thus, protein content is the most important quality consideration in the selection process. Coincidentally, the widespread acceptance of HT and UHT drying has made it possible to produce

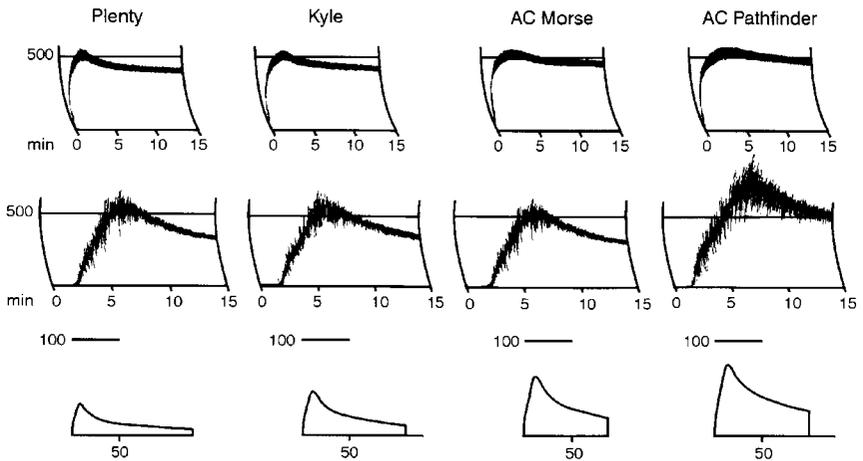


Fig. 6.5 Comparison of the dough strength characteristics of some Canadian durum varieties as determined by alveograph (bottom), mixograph (middle) and farinograph (top) curves (Marchylo *et al.*⁴⁰).

reasonable quality pasta products using low protein semolina. Some countries, however, such as Japan, the USA and Spain, have legislation and labeling laws in place, which stipulate minimum protein levels in the finished product. This requirement, of course, impacts on selection criteria since minimum wheat protein levels must be obtained no matter what the quality potential is for the final product using HT drying.

While HT and UHT drying have become very popular, it is by no means universal. Many different drying regimes are in practice around the world. Some leading manufacturers continue to use LT drying because of tradition, and in the belief that HT and UHT products do not have the texture, flavor and color associated with premium quality LT pasta. In situations where drying temperatures are lower, gluten quality or strength remains a very important selection criterion.

For dried pastas, in particular long goods, major North American and European pasta manufacturers claim that strong gluten durum wheat is preferable. For example, in response to market demand, Italian breeders are developing durum varieties with Alveograph P/L values of about 1.5 to 2.5, and Alveograph W values of around 200 to 250. For top quality long goods, some manufacturers request durum wheat with a W over 300.⁴⁰ Similarly, in response to market demand Canada has recently developed durum wheat varieties with far stronger gluten than conventional strength varieties (Fig. 6.5).

The increasing popularity of instant pastas also may impact on gluten strength requirements, since these pasta have thinner walls and need more strength to stand up to processing. On the other hand, for laminated pasta, which includes much of the increasingly popular fresh pasta, processors have indicated that durum wheat with more extensible and somewhat weaker gluten is preferred

because of superior sheeting properties. Thus, durum wheat or semolina specifications for gluten strength will vary depending on the type of final product being processed, as well as the production and marketing philosophy of the processor.

Another important set of selection criteria is associated with semolina refinement and color and, ultimately, the appearance of pasta. Aesthetics is an integral part of pasta marketing, as evident from the ubiquitous use of transparent packaging which gives customers the opportunity to consider pasta appearance in their purchasing decision. Consumers generally prefer pasta with a deep translucent amber color, although there may be some exceptions in certain countries or segments of the population within a country.

Black specks and bran specks in semolina are important semolina specifications. Black specks and brown specks may be due to poor durum wheat physical condition. Poor milling techniques may also cause them. Black specks can arise from inadequate cleaning, leaving impurities such as ergot and weed seeds in the durum wheat. Bran specks can be the result of improper milling technique, especially improper purifier settings.

In general, pasta color deteriorates (becomes more brown and less yellow) as semolina extraction rate increases because of the combined effects of more bran contamination and elevated levels of oxidative enzymes such as lipoxygenase, polyphenol oxidase and peroxidase.^{41,42} The ash content of the endosperm, from which semolina is derived, is much less than that of the outer regions of the kernel. As a result ash content in semolina is an important specification because it is an indication of semolina refinement. In some countries, such as Italy and France, semolina ash cannot exceed limits specified by government regulations. A limitation of ash content as a semolina refinement index is that endosperm ash content differs widely due to differences among varieties and environment. An alternative method for estimating semolina refinement that relates better to pasta color is to determine the brightness of a wet semolina slurry with a reflectance spectrophotometer.

The yellowness of the final product is influenced by milling, pasta processing conditions as well as by the raw material quality (wheat pigment level). The aesthetic appeal of a bright yellow color makes it a desirable characteristic in durum semolina, although there is no apparent relation between yellowness and cooking quality. The yellow color in durum semolina comes from a carotenoid pigment, xanthophyll. The traditional direct measurement of yellow pigment content in wheat or semolina is to extract with n-butanol or ethanol, followed by spectrophotometric determination at an absorbance of 435.8 nm. The development of affordable computerized spectrophotometers has made rapid precise color analysis of dry semolina possible. Specifications based on tristimulus color coordinates (L^* , a^* , b^*) are becoming more widespread. Care must be taken to ensure that a consistent particle size is used when determining dry semolina color, since semolina will appear increasingly pale as granulation becomes finer. For this reason, in Europe semolina color is often measured instrumentally using discs of dough.

6.6 The future

In many ways the future of the pasta industry is already upon us. In the past twenty years or so there have been major innovations in pasta manufacturing technology that have improved the final product. In particular, as discussed earlier, modern pasta plants are now computer automated. They are also considerably more compact and efficient as the application of modern extrusion and high and ultra high drying technologies have vastly increased production capacity. Further increases in efficiency and product quality have also been achieved through vertical integration of pasta plants and semolina mills. In the future, this will undoubtedly mean that these companies will also become more aware of milling quality as an important processing characteristic in addition to the pasta processing quality of the semolina.

As with many other industries in the world, globalization has impacted on the pasta industry. Large pasta manufacturers or multinational food companies have acquired pasta plants in many countries worldwide. The evolution of the industry undoubtedly will continue along these lines with the world seeing more of the same. The fierce global nature of the competition in this industry will see further rationalization and consolidation of capacity. This development will have implications on durum wheat quality requirements since the philosophy of pasta manufacturing of the parent companies will be integrated into the subsidiaries or branch plants.

The building of super plants with huge capacities will result in increased efficiencies, but with the risk that production problems that shut down lines will be associated with major product losses. These new plants will demand that the durum wheat and semolina that they purchase must be of consistent and uniform quality to minimize any disruptions or plant problems. In addition, the appearance of the finished pasta with specific reference to a bright amber color will probably become more universally important.

The popularity of pasta will continue to increase in many countries with notable potential in Latin America, Asia and the Pacific Rim. Demand for pasta in these parts of the world will increase, and the demand for higher quality pasta made from durum wheat will increase as economies and standards of living improve. As global demand for durum increases, production may lag, and the blending of durum wheat with common or bread wheat may increase in some countries to meet the demand for affordable pasta. Application of higher drying temperatures will enhance the quality of blended products. At the same time, the impact of higher drying temperatures on nutrition, which is currently viewed as an issue mainly in Italy, may become an important consideration, especially where the protein in pasta is viewed as an important source of protein.

The future requirements in the area of durum wheat quality in many ways will not change. In particular, high protein content will continue to be the single most important quality criteria, although it may become less available. The impact of intensive cultivation and crop management practices on the environment, and increased variability in weather conditions, may make it

more difficult for farmers to grow high protein durum wheat. Of course, fluctuating durum wheat prices will influence farmers' decisions on fertilization and, consequently, impact on availability of durum protein. In general, it will be important for plant breeders to develop new durum wheat cultivars with improved potential for protein production under less intensive management practice.

Along with this breeding for higher intrinsic protein potential, plant breeders and quality specialists will need to revisit the traditional concepts of durum wheat and semolina quality. For example, much of the early work that showed the importance of gluten strength to cooked pasta texture was performed at lower traditional drying temperatures. This quality characteristic has been shown, however, to be less important at HT and UHT drying temperatures. Therefore, the specific qualities for durum destined for drying at high temperatures must be determined and incorporated into new durum wheat varieties.

The breeding for durum varieties with novel characteristics for specific markets will also increase in the future. For example, durum wheat varieties may be developed with protein or other quality features specifically aimed for the production of frozen microwavable, instant or retortable pastas. These wheat varieties may have starch characteristics (high amylose) specifically designed to improve cooked pasta quality for such products. Similarly, as people become more health conscious, there may be a niche market for nutraceutical durum wheat (higher fiber, β -glucan) for pasta production. These wheat varieties may be bred using conventional breeding procedures or alternately through genetic modification, depending on consumer acceptance. Currently, durum wheat does not appear to be a target for genetic modification and it remains to be seen when economics and consumer reaction will make this approach more attractive. In general, in the future there will be a wider choice of high quality durum wheat varieties exhibiting a range of quality features, suitable for different products.

6.7 References and further information

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