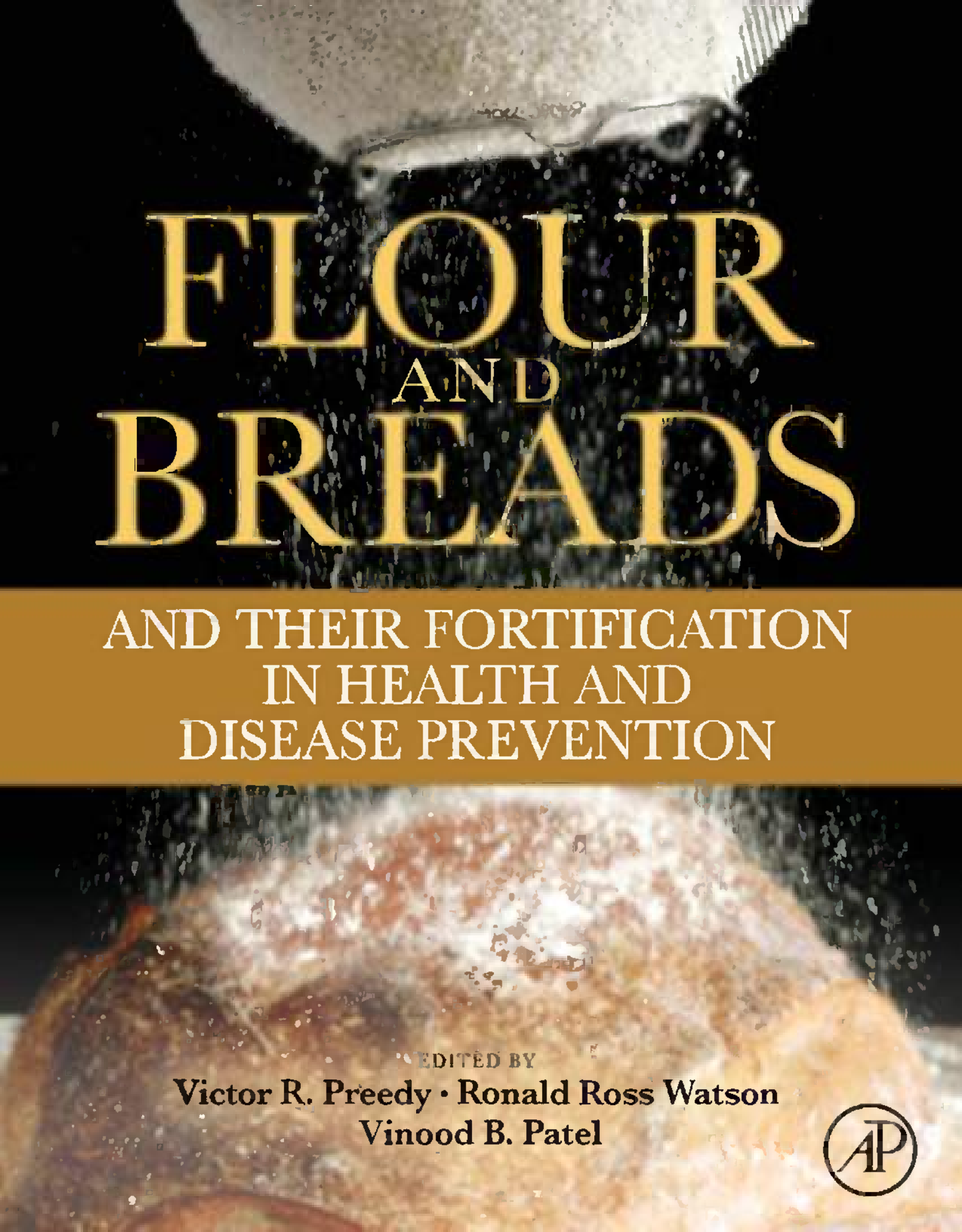
FLOUR
AND
BREADS
AND THEIR FORTIFICATION
IN HEALTH AND
DISEASE PREVENTION
EDITED BY
Victor R. Preedy · Ronald Ross Watson
Vinood B. Patel
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Flour and Breads and their Fortification in Health and Disease Prevention

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Flour and Breads and their Fortification in Health and Disease Prevention

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PREFACE

The historical pictorial evidence for bread making dates back 8000 years, but it is probable that bread was consumed in the unleavened form (without yeast) earlier than this, going hand-in-hand with the cultivation of crops. In some cultures, bread is an integral part of sacred and religious ceremonies.

Currently, bread is an important part of the diet for millions of people worldwide. Its complex nature provides energy, protein, minerals, and many other macro- and micronutrients. However, consideration must be taken of four major aspects related to flour and bread. The first is that not all cultures consume bread made from wheat flour. There are literally dozens of flour types, each with its distinctive heritage, cultural roles, and nutritive contents. Second, not all flours are used to make leavened bread in the traditional (i.e., Western) loaf form. There are many different ways that flours are used in the production of staple foods. Third, flour and breads can be fortified either to add components that are removed in the milling process or to add components that will increase palatability or promote health and reduce disease per se. (In this book, the term "fortification" is used holistically to include statutory and nonstatutory additions.) Finally, there are significant groups of individuals who have intolerance to flours such as wheat, barley, or rye flours.

Finding all this knowledge in a single coherent volume is currently problematical, and *Flour and Breads and their Fortification in Health and Disease Prevention* addresses this.

This book is divided into two main sections:

1. Flour and Breads
2. Fortification of Flour and Breads and their Metabolic Effects

The editors are aware of the difficulties imposed by assigning chapters to different sections and their order, but the navigation of the book is enhanced by an excellent index. The book is also extremely well illustrated, with tables and figures in every chapter.

Where applicable, information on adverse effects or responses is provided. Emerging fields of science and important discoveries relating to flour and bread products are also incorporated in the book. Contributors are authors of international and national standing and leaders in the field.

This book represents a comprehensive coverage of material relating to flour and bread and their constituents. It is essential reading for policymakers, food technologists, marketing strategists, nutritionists, food chemists, health care professionals, research scientists, as well as those interested in flour and breads in general or working in the food industry.

Victor R. Preedy, Ronald Ross Watson,
and Vinood B. Patel

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SECTION 1

Flour and Breads

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CHAPTER 1

The Science of Doughs and Bread Quality

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CHAPTER OUTLINE

INTRODUCTION

Cereals and cereal-based products have constituted the major component of the human diet throughout the world since the earliest times. Cereal crops are energy dense, providing approximately 10–20 times more energy than most juicy fruits and vegetables. Major cereal crops include wheat, rice, corn, and barley. The cereal crop most produced is corn (or maize) (31%), but it has relatively less importance than wheat and rice because it is not directly used for human consumption. Wheat and rice are the most important cereals with regard to human nutrition, and they account for 55% of the total cereal production. Nutritionally, they are important sources of dietary protein, carbohydrates, the B group vitamins, vitamin E, iron, trace minerals, and fibers. It has been estimated that global cereal consumption directly provides approximately 45% of protein and energy necessary for the human diet and only approximately 7% of the total fat (Table 1.1). The specific contribution of wheat to daily food intake corresponds to approximately 20% of the required energy and protein for the human diet (see Table 1.1).

Cereals have a variety of uses as food, although only two cereals, wheat and rye, are suited for the preparation of leavened bread. Nevertheless, wheat is a unique cereal that is suitable for the preparation of a wide diversity of leavened breads that meet consumer demands and requirements worldwide (Figure 1.1) (Rosell, 2007a). Among baked goods, bread has been a staple food for many civilizations. Even today, bread and cereal-based products constitute the base of the food pyramid, and its consumption is recommended in all dietary guidelines. Bread has a fundamental role in nutrition due to the adequate balance of

Flour and Breads and their Fortification in Health and Disease Prevention. DOI: 10.1016/B978-0-12-380886-8.10001-7

TABLE 1.1 Contribution of Cereals to the Daily Food Intake

	Food Consumption (kg/Capita/Year)	Food Consumption (kcal/Capita/Day)	Protein Consumption (g/Capita/Day)	Fat Consumption (g/Capita/Day)
Total		2808.87	75.72	79.63
Cereals	151.07	1302.75	31.62	5.49
Wheat	67.00	518.00	15.34	2.18
Milled rice	54.21	541.92	10.07	1.28
Barley	1.13	8.04	0.23	0.03
Maize	18.54	152.72	3.66	1.22
Rye	0.98	7.42	0.20	0.03
Oats	0.52	2.94	0.12	0.05
Millet	4.05	33.26	0.89	0.35
Sorghum	3.90	32.72	0.97	0.33
Other cereals	0.74	5.73	0.16	0.02

Source: Food and Agriculture Organization (2007).

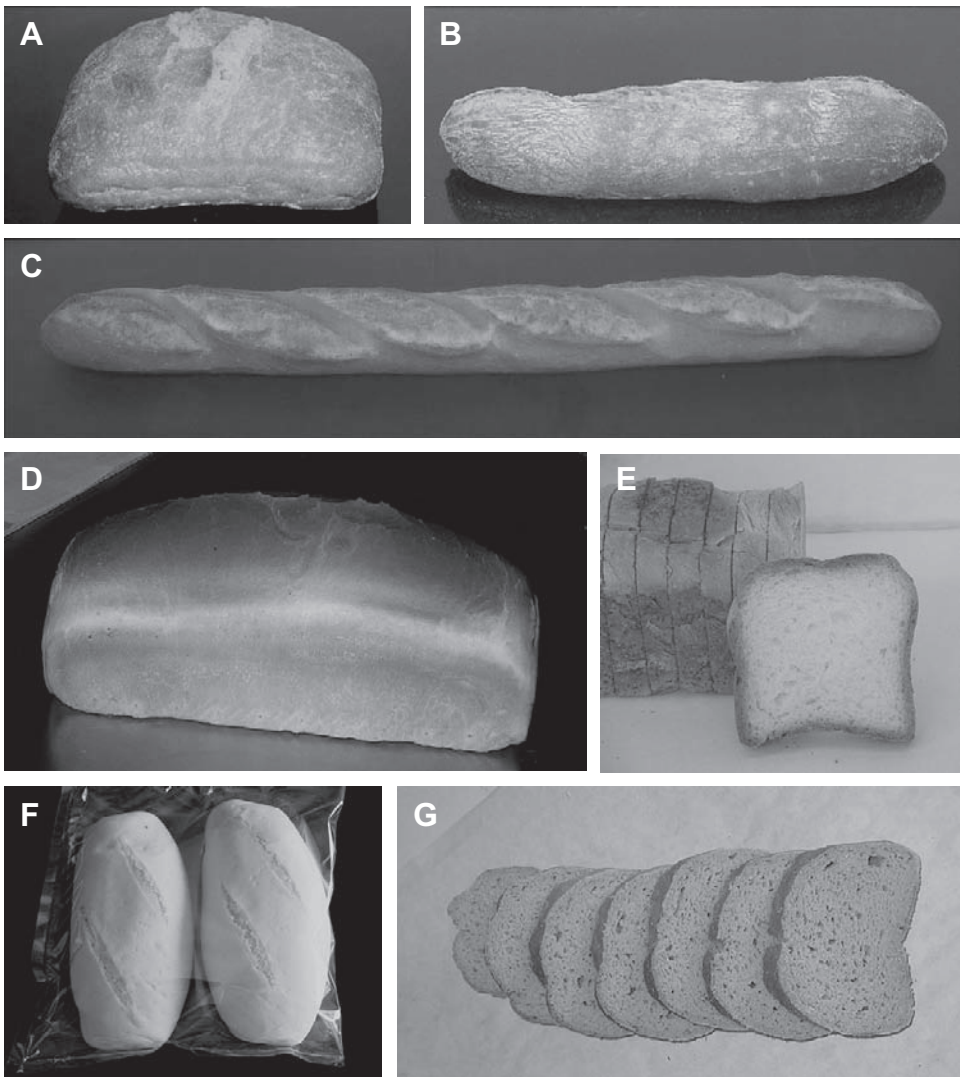

FIGURE 1.1
Different types of breads. There is a wide diversity of leavened breads that meet consumer demands and requirements worldwide. (A and B) Crusty bread named ciabatta, (C) baguette, (D and E) pan bread, (F) partially baked bread, and (G) fiber-enriched bread.

macronutrients in its composition; in addition, it provides some micronutrients and minerals.

NUTRITIONAL VALUE OF CEREALS AND THE IMPACT OF MILLING

All cereal grains have a fairly similar structure and nutritive value, although the shape and size of the seed may be different. In this chapter, wheat is used as a reference because it is the base of more foods than any other grain and the basis for the preparation of leavened bread; hereafter, the discussion refers to wheat grain.

The chemical components of cereals are not evenly distributed in the grain. Table 1.2 provides the nutritive value of the three main different parts in wheat. Bran, which represents 7% of the grain, contains the majority of the grain fiber, essentially cellulose and pentosans. It is a source of B vitamins and phytochemicals, and 40–70% of the minerals are concentrated in this outer layer. The endosperm, the main part of the grain (80–85%), contains mostly starch. It has lower protein and lipid content than the germ and the bran, and it is poor in vitamins and minerals. The germ, the small inner core that represents approximately 21% of the grain, is rich in B group vitamins, proteins, minerals such as potassium and phosphorous, healthful unsaturated fats, antioxidants, and phytochemicals. Cereals are rich in glutamic acid, proline, leucine, and aspartic acid, and they are deficient in lysine. The amino acid content is mainly concentrated in the germ.

Generally, cereal grains are subjected to different processes to prepare them for human consumption. These processes significantly affect their chemical composition and consequently their nutritional value.

The majority of wheat is milled into flour, which can be used to make many types of breads that differ in shape, structure, and sensory characteristics. Milling removes the fibrous layers of the grain; therefore, refined cereals do not have the same nutritional and health benefits as the grain or wholemeal (see Table 1.2). Without the bran and germ, approximately 45% of the grain proteins are lost, along with 80% of fiber, 50–85% of vitamins, 20–80% of minerals, and up to 99.8% of phytochemicals. In addition, important losses of amino acids (35–55%) occur during refining. Some fiber, vitamins, and minerals may be added back into refined cereal products through fortification or enrichment programs, which compensates for losses due to refining, but it is impossible to restore the phytochemicals lost during processing (Rosell, 2007b).

BREAD DOUGH MODIFICATIONS DURING THE BREAD MAKING PROCESS

A brief description of the bread making process is included so that the reader will understand the physical and chemical constraints to which the cereal main biopolymers, constituents of the dough, are exposed during the process (for more detailed information, see Cauvain, 2003). Different alternatives have been developed for adapting bread making to consumer demands and for facilitating the baker's work (Figure 1.2). Bread making stages include mixing the ingredients, dough resting, dividing and shaping, proofing, and baking, with great variation in the intermediate stage depending on the type of product. During mixing, fermenting, and baking, dough is subjected to different shear and large extensional deformations (including fracture), which are largely affected by temperature and water hydration (Rosell and Collar, 2009). Several physical changes occur during the bread making process, in which gluten proteins are mainly responsible for bread dough structure formation, whereas starch is mainly implicated in final textural properties and stability.

In bread making, mixing is one of the key steps that determine the mechanical properties of the dough, which have a direct consequence on the quality of the end product. Mixing evenly

TABLE 1.2 Proximate Composition (%) of Wheat and the Effect of the Milling Process on Nutrient Composition

	Wheat Grain	Bran	Flour	Germ
Energy (kcal)	329.0	216.0	364	360
Total carbohydrate (g)	68.0	64.5	76.3	51.8
Dietary fiber (g)	12.0	42.8	2.7	13.2
Total fat (g)	1.9	4.3	1	9.7
Saturated fat (g)	0.3	0.6	0.2	1.7
Monounsaturated fat (g)	0.3	0.6	0.1	1.4
Polyunsaturated fat (g)	0.8	2.2	0.4	6
Protein (g)	15.4	15.5	10.3	23.1
Amino acids				
Tryptophan (mg)	195	282	127	317
Threonine (mg)	433	500	281	968
Isoleucine (mg)	541	486	357	847
Leucine (mg)	1038	928	710	1571
Lysine (mg)	404	600	228	1468
Methionine (mg)	230	234	183	456
Cystine (mg)	404	371	219	458
Phenylalanine (mg)	724	595	520	928
Tyrosine (mg)	441	436	312	704
Valine (mg)	679	726	415	1198
Arginine (mg)	702	1087	417	1867
Histidine (mg)	330	430	230	643
Alanine (mg)	555	765	332	1477
Aspartic acid (mg)	808	1130	435	2070
Glutamic acid (mg)	4946	2874	3479	3995
Glycine (mg)	621	898	371	1424
Proline (mg)	1680	882	1198	1231
Serine (mg)	663	684	516	1102
Vitamins				
Vitamin A (IU)	9	9	—	—
Vitamin E (mg)	1.0	1.5	0.1	—
Vitamin K (μg)	1.9	1.9	0.3	—
Thiamin (mg)	0.5	0.5	0.1	1.9
Riboflavin (mg)	0.1	0.6	—	0.5
Niacin (mg)	5.7	13.6	1.3	6.8
Vitamin B_6 (mg)	0.3	1.3	—	1.3
Folate (μg)	43	79	26	281
Pantothenic acid (mg)	0.9	2.2	0.4	2.3
Choline (mg)	31.2	74.4	10.4	—
Minerals				
Calcium (mg)	25	73	15	39
Iron (mg)	3.6	10.6	1.2	6.3
Magnesium (mg)	124	611	22	239
Phosphorus (mg)	332	1013	108	842
Potassium (mg)	340	1182	107	892
Sodium (mg)	2	2	2	12
Zinc (mg)	2.8	7.3	0.7	12.3
Copper (mg)	0.4	1.0	0.1	0.8
Manganese (mg)	4.1	11.5	0.7	13.3
Selenium (μg)	70.7	77.6	33.9	79.2

Source: Gramene (2009).

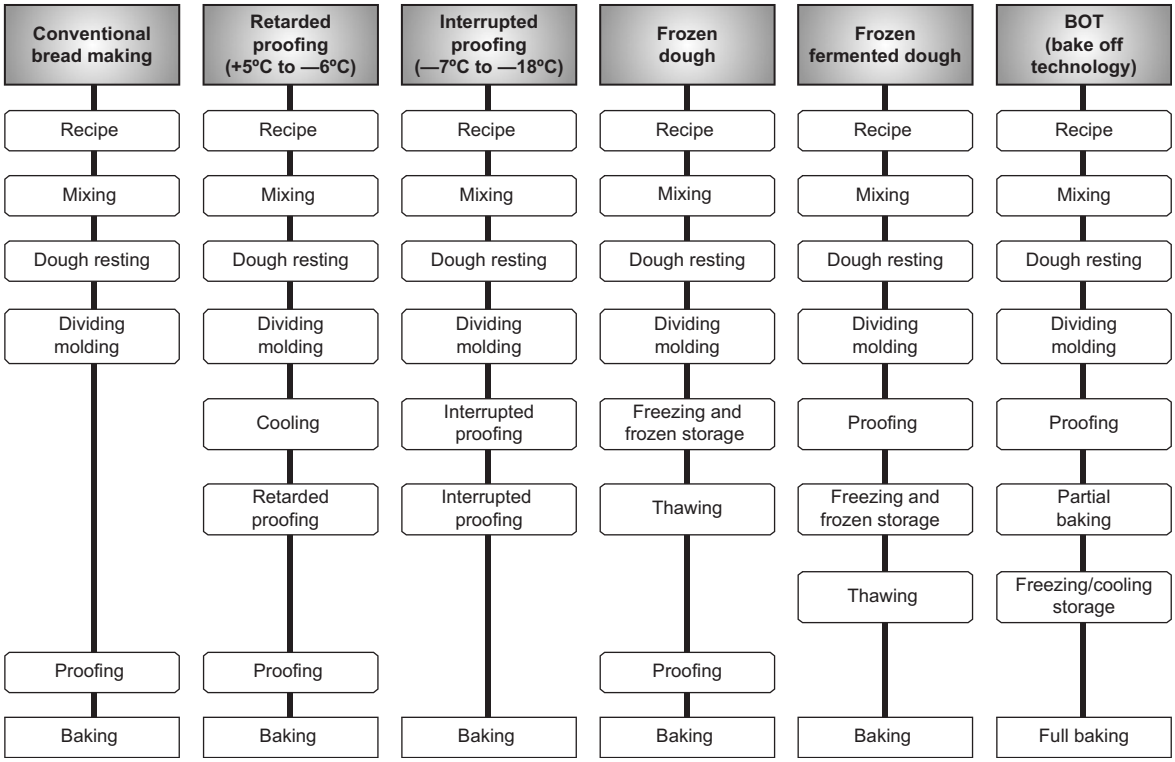

FIGURE 1.2
Current methods of bread making. Different alternatives have been developed for adapting bread making to consumer demands and for facilitating the baker's work. Bread making stages include mixing the ingredients, dough resting, dividing and shaping, proofing, and baking, with great variation in the intermediate stage depending on the type of product.

distributes the various ingredients, hydrates the component of the wheat flour, supplies the necessary mechanical energy for developing the protein network, and incorporates air bubbles into the dough. Each dough has to be mixed for an optimum time to fully develop, and at this stage it offers maximum resistance to extension. The period of barely constant torque determines the dough stability, which is dependent on the flour and mixing method used. Undermixing may cause small unmixed patches that interfere in the proofing stage. Conversely, if the mixing is excessive, dough properties change from good (smooth and elastic) to poor (slack and sticky) (Sliwinski *et al.*, 2004), and a decrease in the consistency is observed, which is attributed to the weakening of the protein network. Bread dough is a viscoelastic material that exhibits an intermediate rheological behavior between a viscous liquid and an elastic solid. Bread dough must be extensible and elastic enough for expanding and holding the released gases, respectively.

During initial mixing, wheat dough is exposed to large uni- and biaxial deformations. Moreover, the material distribution, the disruption of the initially spherical protein particles, and the flour component hydration occur simultaneously, and together with the stretching and alignment of the proteins, this leads to the formation of a three-dimensional viscoelastic structure with gas-retaining properties. The rheological properties of wheat flour doughs are largely governed by the contribution of starch, proteins, and water. The protein phase of flour has the ability to form gluten, a continuous macromolecular viscoelastic network, but only if enough water is provided for hydration and sufficient mechanical energy input is supplied during mixing. The viscoelastic network plays a predominant role in dough machinability and affects the textural characteristics of the finished bread (Collar and Armero, 1996). The viscoelastic properties of the dough depend on both quality and quantity of the proteins, and the size distribution of the proteins is also an important factor. Two proteins present in flour

(gliadin and glutenin) form gluten when mixed with water and give dough these special features. Gluten is essential for bread making and influences the mixing, kneading, and baking properties of dough. According to MacRitchie (1992), two factors contribute to dough strength: the proportion of proteins above a critical size and the size distribution of the proteins. The properties of this network are governed by the quaternary structures resulting from disulfide-linked polymer proteins and hydrogen bonding aggregates (Aussenac *et al.*, 2001). Dough mixing involves large deformations that are beyond the linearity limit, which correlates with nonlinear rheological properties. The characterization of the viscoelastic behavior exceeding the linear viscoelasticity requires specialized devices that record dough consistency when subjected to mechanical stress and/or dual mechanical and temperature constraints (Rosell and Collar, 2009). The stability of failure in single dough bubble walls is directly related to the extensional strain hardening properties of the dough, which plays an important role in the stabilization of bubble walls during baking.

During proofing or fermentation, yeast metabolism results in carbon dioxide release and growth of air bubbles previously incorporated during mixing, leading to expansion of the dough, which inflates to larger volumes and thinner cell walls before collapsing. The growth of gas bubbles during proof and baking determines the characteristics of the bread structure and thus the ultimate volume and texture of the baked product. The yeast breaks carbohydrates (starch and sugars) down into carbon dioxide and alcohol during alcoholic fermentation. Enzymes present in yeast and flour also help to speed up this reaction. The carbon dioxide produced in these reactions causes the dough to rise (ferment or proof), and the alcohol produced mostly evaporates from the dough during the baking process. During fermentation, each yeast cell forms a center around which carbon dioxide bubbles are released. Thousands of tiny bubbles, each surrounded by a thin film of gluten, grow as fermentation proceeds. Kneading or remixing of the dough favors the release of large gas bubbles, resulting in a more even distribution of the bubbles within the dough.

The size, distribution, growth, and failure of the gas bubbles released during proofing and baking have a major impact on the final quality of the bread in terms of both appearance (texture) and final volume (Cauvain, 2003). As the intense oven heat penetrates the dough, the gases inside the dough expand, with a concomitant increase in the size of the dough. As the temperature rises, the rate of fermentation and production of gas cells increases, and this process continues until the temperature of yeast inactivation is reached (approximately 45°C). When proteins are denatured, the gluten strands surrounding the individual gas cells are transformed into the semi-rigid structure that will yield the bread crumb. Endogenous enzymes present in the dough are inactivated at different temperatures during baking. The sugars and breakdown products of proteins released from the enzyme activity are then available to sweeten the bread crumb and participate in Maillard or nonenzymatic browning reactions, which are responsible for the brown color of the crust.

In the past several decades, bread making processes have been adapted to consumer demands, and subzero and low temperatures have been included in flow diagrams for interrupting the processes before or after fermentation, or when partial baking is completed, for obtaining partially baked breads (see Figure 1.1) (Rosell, 2009). These technologies have facilitated the launching of a great number of fresh-baked goods available at any time of the day, and overall they help bakeries bring new products to the market quickly and successfully.

BIOCHEMICAL CHANGES DURING BREAD MAKING

Bread making is a dynamic process with continuous physicochemical, microbiological, and biochemical changes caused by mechanical–thermal action and the activity of the yeast and lactic acid bacteria together with the activity of the endogenous enzymes. The changes in the flour biopolymeric compounds take place during mixing, proofing, and baking. During mixing, dough is exposed to large uni- and biaxial deformations and a continuous protein

network is formed, which is stabilized by disulfide bonds and modified thiol/disulfide interchange reactions. The input of mechanical energy that takes places during kneading confers the necessary energy for distributing flour components, favoring the protein interaction and the formation of covalent bonds between them, which finally leads to the formation of a continuous macromolecular viscoelastic structure. Depolymerization and repolymerization of the sodium dodecyl sulfate-unextractable polymers occurs by the repeated breaking and reforming of disulfide bonds within and between gluten proteins, where glutenin subunits are released in a nonrandom order, indicating a hierarchical structure (Aussenac *et al.*, 2001). Also in this structure, tyrosine cross-links contribute to dough elasticity, suggesting that a radical mechanism involving endogenous peroxidases might be responsible for dityrosine formation during bread making (Tilley *et al.*, 2001).

There is general agreement that gluten is the main contributor to the unique properties of wheat dough properties, affecting dough characteristics and, consequently, the quality of the fresh bread. Gluten is a non-pure protein system, and although the nonprotein components have significant effects, the rheological properties of gluten derive from the properties and interactions among proteins. Gluten proteins comprise two main subfractions: glutenins, which confer strength and elasticity, and gliadins, which impart viscosity to dough. Proteins mainly involved in the viscoelastic properties of the dough are the high-molecular-weight glutenin subunits, which affect dough viscoelasticity in a similar and remarkable way as the water content (Cauvain, 2003). Namely, the mixing process induces an increase in the amount of total unextractable polymeric protein and large unextractable monomeric proteins (Kuktaite *et al.*, 2004). Specifically, the amount of high-molecular-weight glutenins increases with a parallel decrease in the amount of low-molecular-weight glutenins, gliadins, and albumins/globulins (Lee *et al.*, 2002). Mixing also promotes the solubilization of arabinoxylans due to mechanical forces, and this solubilization proceeds further during resting due to endoxylanase activity, in addition to xylosidase and arabinofuranosidase activities (Dornez *et al.*, 2007).

The other large biopolymer that plays an important role in the bread making process is starch. Amylose and amylopectin are the constituents of the starch granule. This biopolymer provides fermentable sugars to yeast and has a significant contribution to dough rheology, especially during the baking process (Cauvain, 2003). Pasting performance of wheat flours during cooking and cooling involves many processes, such as swelling, deformation, fragmentation, disintegration, solubilization, and reaggregation, that take place in a very complex media primarily governed by starch granule behavior. During heating, the native protein structure is destabilized, and unfolding may facilitate sulfhydryl—disulfide interchange reactions and oxidation together with hydrophobic interactions, leading to the association of proteins and, consequently, to the formation of large protein aggregates. Nevertheless, as the temperature increases, the role of the proteins becomes secondary, and changes involving the starch granules become predominant. During this stage, starch granules absorb the water available in the medium and they swell. Amylose chains leach out into the aqueous intergranular phase, promoting the increase in viscosity that continues until the temperature constraint leads to the physical breakdown of the granules, which is associated with a reduction in viscosity. During cooling of the loaf, the gelation process of the starch takes place, in which the amylose chains leached outside the starch granules during heating are prompted to recrystallize. The reassociation between the starch molecules, especially amylose, results in the formation of a gel structure. This stage is related to the retrogradation and reordering of the starch molecules.

In addition to these changes, it must be considered that bread making is a dynamic process with continuous microbiological and chemical changes, motivated by the action of the yeast and lactic acid bacteria, which occur during proofing and the initial stage of baking. Yeasts and lactic acid bacteria contain different enzymes responsible for the metabolism of microorganisms that modify dough characteristics and fresh bread quality. Therefore, wheat flour,

yeasts, and bacterial population of sour doughs are sources of different endogenous enzymes in bread making processes and exert an important effect on dough rheology and on the technological quality of bread (Rosell and Benedito, 2003). Different processing aids, namely enzymes, are also used in bread making to improve the quality of the baked products by reinforcing the role of gluten, providing fermentable sugars, and/or contributing to stabilize the hydrophobic–hydrophilic interactions (Rosell and Collar, 2008).

Numerous biochemical changes occur during bread making that have direct effects on the sensory attributes and nutritional quality of the finished product. The contribution of low-molecular-weight proteins to the taste and flavor of bread depends on the content of peptides rich in basic and hydrophobic amino acids released during fermentation and baking, the proportion of hydrophilic peptides in unfermented bread, and the balance of endo- and exoprotease activities during those stages. Changes in the total or individual content of amino acids and peptides during the different steps of bread making modify the organoleptic characteristics of the bread (Martinez-Anaya, 1996). Amino acids are absorbed by yeast and lactic acid bacteria and metabolized as a nitrogen source for growth, resulting in an increase in the amount of gas produced, raising the alcohol tolerance of yeast and improving the organoleptic and nutritional quality of bread. They can also be hydrolyzed by the action of proteolytic enzymes from both flour and microorganisms on proteins as well as by yeast autolysis. The amino acid profile during bread making reveals that the total amino acid content (particularly for ornithine and threonine) increases by 64% during mixing and then decreases 55% during baking, with the most reactive amino acids being glutamine, leucine, ornithine, arginine, lysine, and histidine (Prieto *et al.*, 1990). Free amino acids in wheat flour and dough play an important role in the generation of bread flavor precursors through the formation of Maillard compounds during baking. In fact, leucine, proline, isoleucine, and serine reacting with sugars form typical flavors and aromas described as toasty and breadlike, whereas excessive amounts of leucine in fermenting doughs lead to bread with unappetizing flavor (Martinez-Anaya, 1996). The specific metabolic activities of fermentation microorganisms are responsible for the dynamics in nitrogen compounds, showing different metabolic rates for acidic, basic, aliphatic, and aromatic amino acids. Lactic acid bacteria contain proteases and peptidases, which release into the media amino acids and peptides that are easily metabolized by yeast and lactic acid bacteria, showing different nutritional requirements and exoproteolytic and endoproteolytic activities depending on the strain of lactic acid bacteria (Collar and Martinez-Anaya, 1994). In general, wheat doughs started with lactic acid bacteria show a gradual increase in valine, leucine, and lysine during fermentation, and there is also an increase in proline but only during the initial hours of proofing. In addition, the action of proteinases and peptidases from lactic acid bacteria on soluble polypeptides and proteins results in an increase in short-chain peptides that contribute to plasticize the dough and give elasticity to gluten. Jiang *et al.* (2008) observed a decrease in 17 amino acids in steamed bread; alanine underwent the highest loss (17.1%), followed by tyrosine (12.5%), and leucine was the least affected amino acid.

Protein–lipid interactions in wheat flour dough also play an important role because both lipids and proteins govern the bread making quality of flour. Lipids have a positive effect on dough formation and bread volume, namely polar lipids or the free fatty acid component of the nonstarch lipids, whereas nonpolar lipids have been found to have a detrimental effect on bread volume (MacRitchie, 1983). During mixing, more than half of the free lipids in flour are associated with gluten proteins, although there is no consensus about the type of interactions between lipids and proteins. However, evidence has been presented that nonpolar lipids are retained within the gluten network through hydrophobic forces, involving the physical entrapment of lipids within the proteins (McCann *et al.*, 2009). The same study suggests that glycolipids are associated with glutenins through hydrophobic interactions and hydrogen bonds, whereas the phospholipids presumably interact with either the gliadins or the lipid-binding proteins.

Vitamin content is also affected during the bread making process. The yeasted bread making process leads to a 48% loss of thiamine and 47% loss of pyridoxine in white bread, although higher levels of these vitamins can be obtained with longer fermentations (Batifoulier *et al.*, 2005). Native or endogenous folates show good stability in the baking process, and even an increase in endogenous folate content in dough and bread compared with the bread flour was observed by Osseyi *et al.* (2001). Nevertheless, the bread making process with yeast fermentation is beneficial for reducing the levels of phytate content with the subsequent increase in magnesium and phosphorus bioavailability (Haros *et al.*, 2001).

BREAD QUALITY: INSTRUMENTAL, SENSORY, AND NUTRITIONAL QUALITY

Bread quality is a very subjective term that greatly depends on individual consumer perception, which in turn is affected by social, demographic, and environmental factors. The perception of bread quality varies widely with individuals and from one bread to another. Scientific reports focused on the bread making process or recipes usually refer to instrumental methods for assessing quality, whereas studies focused on consumer preferences highlight the significant relationship between sensory quality and consumer perception. Alternatively, healthy concepts related to nutritional value are emerging as fundamental quality attributes of bread products (Table 1.3). Therefore, the global concept of bread quality could be integrated by instrumental attributes, those that can be objectively measured; sensory sensations including descriptive attributes related to consumer quality perceptions; and nutritional aspects related to healthiness and functionality of the bread products.

Regarding instrumental quality (see Table 1.3), due to the existence of a great variety of breads derived from different wheat grains, bread making processes, and recipes, it is almost impossible to identify specific features for assessing bread quality. Consequently, different features have been defined and quantified to evaluate breads, including volume (rapeseed displacement), weight, specific volume, moisture content, water activity, color of crust and crumb, crust crispiness, crumb hardness, image analysis of the cell distribution within the loaf slice, and volatile composition. All these instrumental measurements have been extensively used for investigating the impact of different flours, ingredients, processing aids, and bread making processes on baked products (Cauvain, 2003; Rosell and Collar, 2008). These measurements provide objective values that, although they do not reflect consumer preferences or freshness perception, are very useful for comparison purposes when the aim is the improvement of intrinsic bread features perceived as bread quality attributes.

The perceived quality of bread is a complex process associated with sensory sensations derived from product visual appearance, taste, odor, and tactile and oral texture. Generally, perceived quality of bread is intimately linked to freshness perception. Consumer test provides an important tool for understanding the consumer expectations of different bread varieties. A number of surveys have been conducted to determine consumer perceptions of and preferences for bread products (Dewettinck *et al.*, 2008; Heenan *et al.*, 2008; Lambert *et al.*, 2009). A descriptive sensory analysis carried out on 20 commercial bread types allowed consumer segmentation into three clusters: (1) preference for porous appearance and floury odor; (2) preference for malty odor and sweet, buttery, and oily flavor; and (3) preference for porous appearance, floury and toasted odor, and sweet aftertaste (Heenan *et al.*, 2008). In a European survey on consumer attitudes toward breads, two main groups were defined: frequent (daily) buyers with a focus on quality and pleasure and less frequent buyers (once a week) with a more pronounced interest in nutrition, shelf life, and energy (process) (Lambert *et al.*, 2009). The first group was called the "crust group" and the second one the "crumb group."

Consumers are becoming more conscious about the relationship between nutrition and health. Currently, innovations in bread are mainly focused on nutritionally improving bread

TABLE 1.3 Overview of the Parameters That Can Be Used for the Quality Assessment of Breads

Instrumental quality	Sensory analysis
Specific volume	Visual appearance
Crust color	Odor
Crumb texture fresh	Tactile and oral texture
Hardness	Taste
Springiness	Overall acceptance
Cohesiveness	Nutritional quality
Chewiness	Proximate composition
Resilience	Carbohydrates
Crust indentation	Proteins
Hardness	Fat
Area	Dietary fiber
Crust thickness	Glycemic index
Water activity	Load index
Moisture content	
Width:height ratio	
Crumb cell analysis	
Number of alveoli	
Average area	
Average diameter	
Circularity	
Volatile compounds	

through enrichment or the use of different flours (Collar, 2007; Rosell, 2007b). Particularly, older consumers and those who are attentive to their health are the most concerned about nutritional aspects of bread (Lambert *et al.*, 2009). Although labels related to the composition of bread are mandatory only for packed breads (regulatory constrain), the majority of consumers would prefer to have that information for all bread varieties. Despite the fact that the nutritional composition of bread varies with the type of bread, bread is an energy-dense product due to the carbohydrate content in the form of starch. It also provides important amounts of protein and dietary fiber and does not contain cholesterol (Table 1.4). Bread is the

TABLE 1.4 Nutritional Information of Different Commercial Bread Varieties

	Nutritional Composition					
Bread Variety	**Energy Value (kcal/100 g)**	**Carbohydrates/ Sugars (g/100 g)**	**Fats/Saturated (g/100 g)**	**Proteins (g/100 g)**	**Dietary Fiber (g/100 g)**	**Sodium (g/100 g)**
White loaf	268	53/2.5	1.8/1.0	9.8	1.8	0.5
Baguette	279	53/1.9	1.8/0.7	9.9	6.6	0.7
White wheat pan bread	232	43/4.3	3.2/0.4	7.9	2.5	0.5
Whole wheat pan bread	247	41/6.0	3.0/1.0	13.0	7.0	0.5
Fiber-enriched pan bread	221	43/4.3	1.0/0.2	9.6	4.2	0.7
Protein-enriched wheat bread	245	44/1.0	2.0/0.0	12.0	3.0	0.5
Reduced-calorie wheat bread	198	44/3.0	2.0/0.0	9.0	12.0	0.5
Mean	229	43/3.7	2.2/0.3	10.3	5.7	0.5
SD	20.1	1/1.9	0.9/0.4	2.1	3.9	0.1

most important source of dietary fiber, although the content of this macronutrient decreases significantly during the refining process; as such, wholemeal breads are the recommended bread type for healthy diets.

CONCLUSION

Bread dough is a versatile matrix that, after proofing and baking, yields a variety of bread products. Traditionally, bread has been seen as a staple food, with nearly ubiquitous consumption worldwide, because it constitutes an important source of energy and provides most of the nutrients and important micronutrients. However, changes in consumer eating patterns have resulted in the modification of the perception of bread from a basic food to a nutritious and healthy product, a vehicle of functional ingredients, or the target product when nutrition deficiencies are detected in the population. Namely, bread not only contains traditional nutrients but also provides other compounds that are beneficial to health and well-being. The nutritive and sensory values of cereal grains and their products are, for the most part, inferior to those of animal food products. Nevertheless, genetic engineering, amino acid and other nutrient fortification, complementation with other proteins (notably legumes), milling, heating, germination, and fermentation are methods employed for improving the nutritive value of breads. Research has also introduced novel flour and traditional grains, such as amaranth, quinua, sorghum, or spelt, to improve the nutritional value of baked products and also to meet the demands and requirements of targeted groups with special food needs.

SUMMARY POINTS

- Worldwide, bread is one of the most consumed foodstuffs.
- Bread making stages include mixing the ingredients, dough resting, dividing and shaping, proofing, and baking, with great variation in the intermediate stage depending on the type of product.
- Bread making is a dynamic process with continuous physicochemical, microbiological, and biochemical changes.
- A global concept of bread quality could be integrated by instrumental attributes objectively measured, sensory sensations, and nutritional aspects.
- Bread has a fundamental role in nutrition derived from the adequate balance of macronutrients in its composition; moreover, it provides some micronutrients and minerals.
- Some fiber, vitamins, and minerals may be added back into refined cereal products through fortification or enrichment programs.

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CHAPTER 2

Monitoring Flour Performance in Bread Making

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CHAPTER OUTLINE

LIST OF ABBREVIATIONS

MCC Multivariate control chart
NIR Near-infrared
PCA Principal component analysis
PLS Partial least squares
RMSECV Root mean square error in cross-validation

INTRODUCTION

The food industry needs to keep the product quality perceived by the consumer as constant as possible. This is not easy to achieve given the inner unevenness of raw materials, which can depend on several sources of variability. The baking industry is influenced by the irregularity of wheat flour properties: During the year, flour batches present high variability in terms of rheological parameters, which depends on wheat varieties, employed as pure or in mixtures of different proportions, and on the harvesting time, weather conditions, and agronomic techniques—all of which play a role, sometimes not completely understood, in

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determining wheat performance (Carcea *et al.*, 2006). Thus, flour batch variability influences dough and bread properties to a great extent. Moreover, the possibility to know in advance which flour batches could lead to a defective final product and for which peculiar flour characteristics could allow adapting bread recipes to recover final product acceptability.

Commonly, a restricted pool of flour rheological properties are considered as "performance indicators" to act on the bread recipe and process conditions of mixing, leavening, and baking phases and correct them on an "experience basis" to maintain acceptable final product quality. One of the most limiting aspects of this approach is that the technological parameters are considered in a univariate way, thus losing the effect of the correlation of these properties on flour performance. Also, their effect on bread is usually evaluated in a "trial-by-error" approach by adjusting process parameters and recipe, verifying the outcome on the subsequent production, and repeating the modifications until bread properties become optimal.

Li Vigni *et al.* (2009) proposed an approach, based on multivariate control chart (MCC) methodology (Kourti, 2006), that allows monitoring of flour quality and early identification of flour batches potentially leading to poor performance in production. Using this approach, all rheological properties of incoming flour batches are evaluated multivariately, and these values are projected on a model based on historical data, thus highlighting potential deviances from optimal flour batches employed in the past.

In this chapter, we extend this strategy to a more general framework that considers routine flour quality control at the miller and routine control of incoming flour batches at the bakery:

1. The determinations routinely performed at millers' laboratories are used to elaborate an MCC based on flour variability in terms of rheological properties (rheoMCC) to evaluate if a new delivered sample presents technological characteristics that are either comparable to or significantly different from previous flour deliveries. This chart has to be modeled on a sufficiently wide period of data collection to be robust both to harvesting year and to flour mixture composition variations. Moreover, contribution plots allow the identification of the rheological properties responsible for these deviances. This information will help millers to control the quality of the flour they produce.
2. The rheoMCC can be used by bakeries to orient bread recipe modification at a very early stage of production. However, taking into account the steps involved in flour storage and delivery, a greater benefit may come from the use of an MCC elaborated on the basis of near-infrared (NIR) spectra acquired *in situ* for each flour delivery. This fast, noninvasive technique allows for monitoring of every incoming flour batch directly at delivery.
3. Both kinds of information can be matched with the quality parameters monitored for bread products.

This approach offers an interesting tool to detect anomalous flour batches; however, the relationship between technological parameters and bread properties is often poorly known. Several studies have dealt with the influence of flour composition on bread quality (Goesaert *et al.*, 2005), focusing on the role of the protein fraction because it is well-established that the gluten network determines dough extensibility and tenacity. Different studies have noted that it is not the global content of proteins that influences flour performance but, rather, the amount of certain protein subfractions (Peña *et al.*, 2005), such as glutenins [high molecular weight (HWM) and low molecular weight (LMW)] and gliadins (α, β, γ, and ω components), and their ratio (Uthayakumaran *et al.*, 1999). Thus, Li Vigni *et al.* (2010) addressed the study of the influence of flour batch properties on bread quality by monitoring the protein content of flour batches employed in real industrial production during a period of 2 years. Here, the main results are matched to flour quality from a technological point of view.

TECHNOLOGICAL ISSUES

A principal issue regarding wheat flour and bread quality is the rapidity with which one can gather this information, process it, and determine how to intervene in the process—for example, how to optimize process steps considering flour natural variability so as to maintain bread properties as constant as possible. Bread quality can be measured quickly by imaging techniques, which convert bread pictures in parameters such as dimensions, texture, and color. In this application, an on-line image acquisition system was used (Q-Bake, EyePro System S.R.L.) to measure diameter, height, and upper and lower color of bread and to purge defective product automatically.

At millers' laboratories, flour chemical and rheological properties are routinely analyzed both as a traditional way to evaluate flour performance and to comply national regulations on bread wheat commercial classification. Therefore, these determinations can be used as an early index of wheat flour potential performance. The rheological properties considered here were determined using a Brabender Farinograph and Extensigraph, a Chopin Alveograph, and a Newport Rapid Visco Analyser. Chemical properties (protein content, ashes, and humidity) were measured using a Foss NIRsystems 5500. Rheological properties are laborious and time-consuming to obtain, and a faster method to assess incoming deliveries, such as NIR spectroscopy, should be considered. Measurements were performed with a Bruker Vector-22N FT-NIR spectrophotometer equipped with an optical fiber (spectral working region, 9000 cm^{-1} to 3940 cm^{-1}; resolution, 2 cm^{-1}; 32 scans).

Although rheological properties are routinely measured to characterize flour deliveries, the microscopic correspondence to these macroscopic measurements in terms of flour chemical composition, and gluten components ratios in particular, has not been ascertained. Thus, a detailed investigation (Li Vigni *et al.*, 2010) of gluten composition, in terms of gliadin and glutenin subfractions, was conducted on flour batches according to the procedure proposed by Wieser *et al.* (1998) for protein subfraction separation and characterization by means of reverse-phase high-performance liquid chromatography. Because this procedure is laborious and time-consuming, it cannot be used routinely to obtain information on flour; however, it helps in the evaluation of gluten quality and its role in flour performance.

To elaborate MCC, several approaches can be chosen according to multivariate statistical process control methods. Rheological properties and NIR spectra are punctual measurements on flour batches and deliveries; thus, they can be processed with principal component analysis (PCA) for model creation. PLS Toolbox 5.2 (Eigenvector Research) has been used for PCA. Bread quality data, instead, are recorded on-line and are subject to the phase variability (alternation of raw materials loading, processing, and product exit) of a batch process, thus requiring a batch statistical process control approach (Camacho *et al.*, 2008; Wold *et al.*, 2009). Partial least squares (PLS) batch modeling was conducted by SIMCA-P+ 11 (Umetrics AB).

MULTIVARIATE CONTROL CHART METHODOLOGY

A more effective way to control an industrial process is to develop MCCs instead of classical univariate control charts. MCCs are built by means of a multivariate projection method (i.e., PCA or PLS) applied to a set of reference data in such a way as to consider different variables and the possible interactions among them at the same time. A key step in the definition of an MCC is the choice of the target process conditions, corresponding to a constant or optimal performance—that is, when the system is under control and almost stable through time. The evaluation of the distance of new data—projected on the model—from the model allows one to follow the process evolution. If the statistics for new samples fall within the T^2 and/or Q confidence limit, the new batch is considered in control; otherwise, the process has changed from its usual behavior.

In particular, two cases are possible:

- T^2 out of control: The model is still able to describe the process, but the new batch presents unusual values for some of the variables. In this situation, care should be used because, for example, the new sample may be a prediction outlier or the model may need to be updated.
- Q out of control: The new data present a particularity, which was not considered and described by the model.

Contribution plots (Westerhius *et al.*, 2000) report the contribution of each of the original variables to the calculated statistic, thus giving information on the causes of process deviation. To capture the variables responsible for deviation, a confidence interval has to be associated with the contribution values—that is, problematic variables will have a value of contribution outside the confidence interval. In the current work, the 95th and 99th percentile values of the contributions to Q and T^2 distances were considered as limits to have a distribution-free estimate. Moreover, they have been calculated on test set samples falling below the critical Q and T^2 values at the 95% confidence limit to consider the natural variability of the rheological properties for model-independent, not extreme, samples.

Here, we propose MCCs for flour quality control and to evaluate whether the performance in production of incoming wheat flour batches is comparable to (or significantly different from) that of previous deliveries. To this aim, we considered different sets of data, namely "bread quality data," "flour properties data," and "NIR data." Flour properties data are collected by the miller and used for the elaboration of rheoMCC. NIR data can be collected at the bakery for every incoming flour batch at the delivery stage and used to elaborate NIR-based MCCs (nirMCC) for postdelivery quality control of the main raw material. Moreover, flour batches showing a baking behavior considered "in control" can be indicated *a posteriori* by inspecting MCCs based on bread quality data to highlight flour-peculiar features influencing baking. This scheme is very general and may be applied in different milling and bread production contexts.

As an example, we illustrate the application in the production of a particular kind of bun, whose quality is assessed in terms of height, diameter, and color of the upper and lower part of the bun.

Bun quality data are batch data, monitored on-line during baking for each bun produced while different batches of flour are loaded. In this case, a total of 79 844 observations (every 2 min) of the four quality properties were recorder for the 58 batches reported in Table 2.1. A batch PLS model was developed for the centered and scaled data matrix using the time period in which one flour batch is continuously used in bun production as y variable. Such a model allows information to be obtained on how each batch has progressed in time, and Q and T^2 distances can be considered to detect which flour batches of the bun had the most production time above the considered confidence limits.

The goal of rheoMCC and nirMCC is to rapidly evaluate how and why a given flour delivery is distant from the model built on the historical data set; thus, a wide data set was collected to comprise different harvesting years and flour compositions (see Table 2.1). Moreover, in the training set for MCCs, batches and deliveries with extreme properties should be kept out so that the model is able to learn from past flour batches with a common profile.

The training set was chosen—with both flour properties data and NIR data—using the following probabilistic approach:

- The total number of collected samples, for each data set, was randomly divided into training and test sets according to a 2:1 partition, and the corresponding PCA model was computed. This procedure was repeated 500 times: As a result, all the samples were considered in the training set in approximately 70% of the total runs and in the test set for the remaining 30%. Model dimensionality was chosen as the root mean square error in cross-validation (RMSECV; leave-one-batch-out) minimum.

TABLE 2.1 Prospects of the Wheat Flour Batches Sampled[a]

Harvest	Dates	Symbol	Batches (Deliveries)	Batch ID	NIR (Samples)	Protein Analysis (Batches)	Mixture Composition			
							W1	W2	W3	Others
2007	3/20/07 to 5/19/07	Circle	4 (16)	—	—	—		80%	20%	
	5/12/07 to 9/11/07	Square	13 (53)	1–4, 6	34	—		74%	26%	
	7/28/07 to 4/9/08	Diamond	28 (91)	5, 7–10	29	—	75%	25%		
				11–24	—	—				
				25–31	42	25–31				
	6/6/08 to 7/30/08	Downward triangle	7 (16)	32–38	—	—	30%	30%	40%	
2008	7/22/08 to 8/14/08	Upward triangle	2 (6)	39	—	—	80%	20%		
	8/8/08 to 9/2/08	Cross	3 (9)	40	—	—	100%			
	9/4/08 to 9/17/08	Leftward triangle	2 (7)	41–42	—	—	98%			2% gluten
	9/18/08 to 12/30/08	Rightward triangle	10 (41)	43–52	—	—	69%	10%	20%	1% gluten
2009	1/3/09 to 3/7/09	Six-pointed star	6 (30)	53–54	—	—	70%			30% (W2 + others)
				55–58	35	55–58				
Total			75 (269)	58	140	11				

[a]*The table reports the number of flour batches and deliveries (column 4) divided by harvest year (column 1) and period of employment in production (column 2). ID numbers (column 5) are used in figures to identify batches. The last four columns indicate the flour formulation in terms of wheat varieties.*

- From the 500 PCA models, the list of samples outside the critical Q and T^2 values at 95% confidence limits was collected. For each sample, the frequencies of each sample above the critical Q and the critical T^2 were computed both when a given sample was in the training and in the test set. These frequencies were employed to identify samples that were particularly extreme in comparison to the mean of the model.
- The training set for the PCA model on which the MCC is based was chosen by excluding those samples that were extreme in more than 50% of the runs, according to Q or T^2 values, and also randomly excluding a number of samples in order to respect the 1:2 proportions with the training set. Random choice was done so that each batch was represented with a maximum of 20% of its samples in order to evaluate model robustness in correctly accepting samples with properties generally similar to those of the mean of the model.

Thus, of the total 269 samples of the rheological data, the test set included the 30 samples presenting Q values and the 8 samples presenting T^2 values above the confidence limit for more than 50% of the total occurrences and 52 additional samples randomly chosen among the remaining ones. The rheoMCC training and test sets were composed of 179 and 90 samples, respectively. Regarding the 140 samples of the NIR data, the test set included the 13 samples presenting Q values and the 6 samples presenting T^2 values above the confidence limit for more than 50% of the total occurrences and 27 additional samples randomly chosen among the remaining ones. The nirMCC training and test sets were composed of 94 and 46 samples, respectively.

MONITORING FLOUR PERFORMANCE ON THE BASIS OF CHEMICAL AND RHEOLOGICAL PROPERTIES

Figure 2.1 shows the rheoMCC Q chart with the test set samples projected on the considered model; less than 2% of all the samples fall above the 99% confidence limit, and less than 7% fall above the 95% confidence limit, for the T^2 chart (not shown). The model is quite robust in

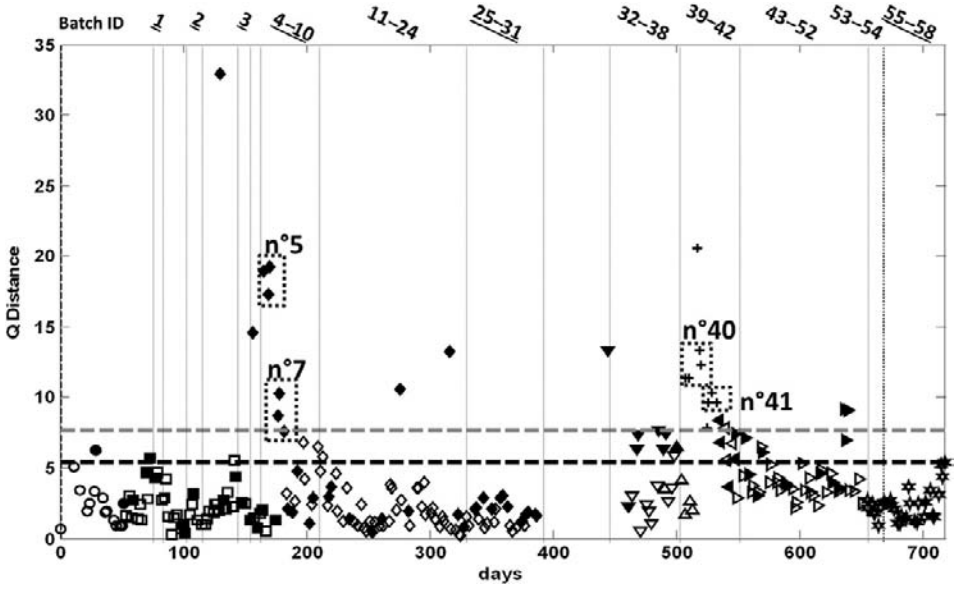

FIGURE 2.1
MCC based on wheat flour properties. *Q* distance to PCA model (five PCs as a minimum RMSECV—CV method: leave-one-batch-out). Samples ordered for delivering days; symbols correspond to wheat mixture (see Table 2.1). Black symbols, test set samples; horizontal gray and black lines, Q_{crit} at 99% and 95% confidence limits, respectively; vertical dotted lines, flour batch IDs introduced in Table 2.1.

terms of false positives (samples that present a significant *Q* distance from the model while not in the test set or among the randomly chosen, "normal" deliveries): All of the samples of the training set fall below the critical values of *Q* when the 99% confidence limit is chosen.

The samples highlighted in Figure 2.1 correspond to flour batches that present a *Q* distance from the model significantly higher than the critical values at the selected confidence limits for all their deliveries. This means that all the deliveries for batches 5, 7, 40, and 41 present rheological properties that are particularly different from those of the flour batches previously employed in production at the bakery. The operator can thus have immediate information on this, which would not have been possible if only a few properties were evaluated one at time, and raise a warning about the potential behavior in production of this batch from its first delivery.

These batches had already been employed in production at the time when the model was elaborated, which means that an indication of their performance in production can be assessed by considering the multivariate bread quality chart shown in Figure 2.2. It is possible to notice that most of the flour batches have led to a portion of bread production that scores above the *Q* confidence limits (a similar behavior is observed for the T^2 statistic; not shown). This can be explained by considering that the recipe is modified empirically during use of a flour batch on the basis of the outcome of the first deliveries whenever the product does not meet the required specifics: These modifications can strongly influence, both positively and negatively, the quality of bread. However, it is clear that batches whose deliveries fall above the confidence limit in rheoMCC usually lead to bread whose properties are mostly above the critical *Q* values. In particular, batches 5, 7, and 39—43 show both extreme values for the technological properties and a non-optimal performance in bread production.

Accessing the contribution plots for the two sets of data allows the interpretation of which kind of defectiveness in bread causes the production to fall above the *Q* critical value and which flour properties are peculiar to these batches. As an example, Figure 2.3 shows the contribution plot corresponding to batch 7.

Considering the rheological properties (see Figure 2.3a), there is a significant positive contribution of ashes, whose high values in flour are reported to contribute to a darker color in baking products, and of farinographic properties of the dough, such as low water absorption (negative value contribution), which indicates that the flour can take up less

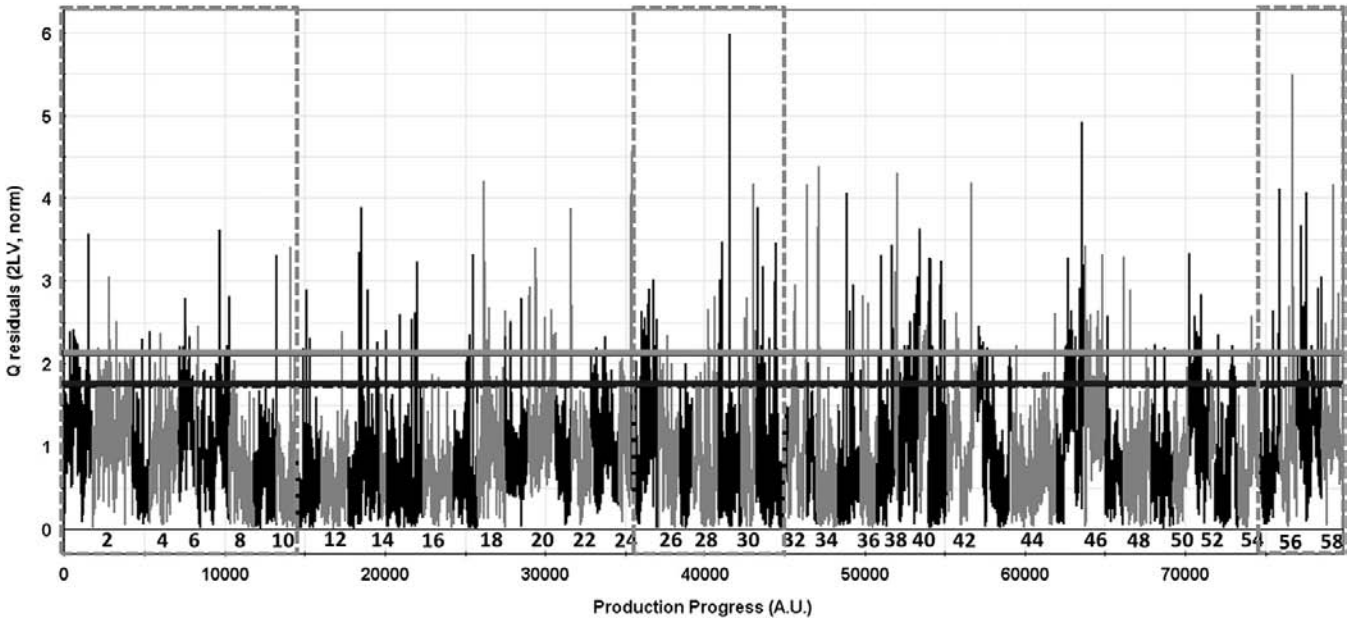

FIGURE 2.2
MCC based on bread quality data. *Q* distance from batch-PLS model (two PCs, explaining 56% of X-block variance). Dashed boxes, flour batches with corresponding NIR samples; horizontal gray and black lines, Q_{crit} at 99% and 95% confidence limits, respectively. Flour batches are numbered progressively in order of employment; alternated black and gray colors, and even batches numbering only, are used for clarity.

water. This, together with the significant contributions of the developing time and alveographic parameter *W*, which are associated with dough strength, can lead to non-optimal dough behavior in the leavening step so that the final product presents dimensions beyond specifications. The previously mentioned defectiveness can indeed be found in the bread produced from flour batch 7, as it is shown by *Q* contributions for the Q-Bake properties (see Figure 2.3b). Here, only the measurements falling above the *Q* critical value at the 95% confidence limit are represented as black dots: These points correspond to Q-Bake readings of several bread production batches obtained from that particular flour batch. Bread obtained from flour batch 7 shows a significant *Q* contribution of the upper color and bun diameter, both with a positive sign, which means a darker upper part and a larger diameter. It also shows a contribution of lower color with a negative sign, meaning that bread has a lighter color on its bottom part, and some bun batches with a smaller diameter (negative sign of the correspondent contribution).

FAST MONITORING OF FLOUR BATCHES BY NIR SPECTROSCOPY

The NIR spectra acquired on flour deliveries at the bakery have been considered to create the nirMCC, of which the *Q* chart is shown in Figure 2.4 (the T^2 distance, not shown, was below the critical value at the 99% confidence limit for all the deliveries). The flour deliveries that have been experimentally monitored belong to the flour batches indicated in Table 2.1 and highlighted in Figures 2.1 and 2.2. Some deliveries fall above the 95% critical limit, such as the first deliveries of batch 1, and in particular the deliveries with a *Q* value higher than the critical 99% confidence limit belong to batch 7 and batch 31. It is interesting that although the considered deliveries of batch 1 and 7 have a corresponding higher *Q* distance in the rheoMCC, batch 31 results are similar to the model based on historical rheological data. Multivariate bread quality evaluation (see Figure 2.2) and the comments of the personnel at the bakery indicated the batch was problematic, which suggests that either process and recipe modifications were not suitable for that batch or some modifications of the flour occurred during transportation or storage. The latter consideration suggests that the NIR spectrum is

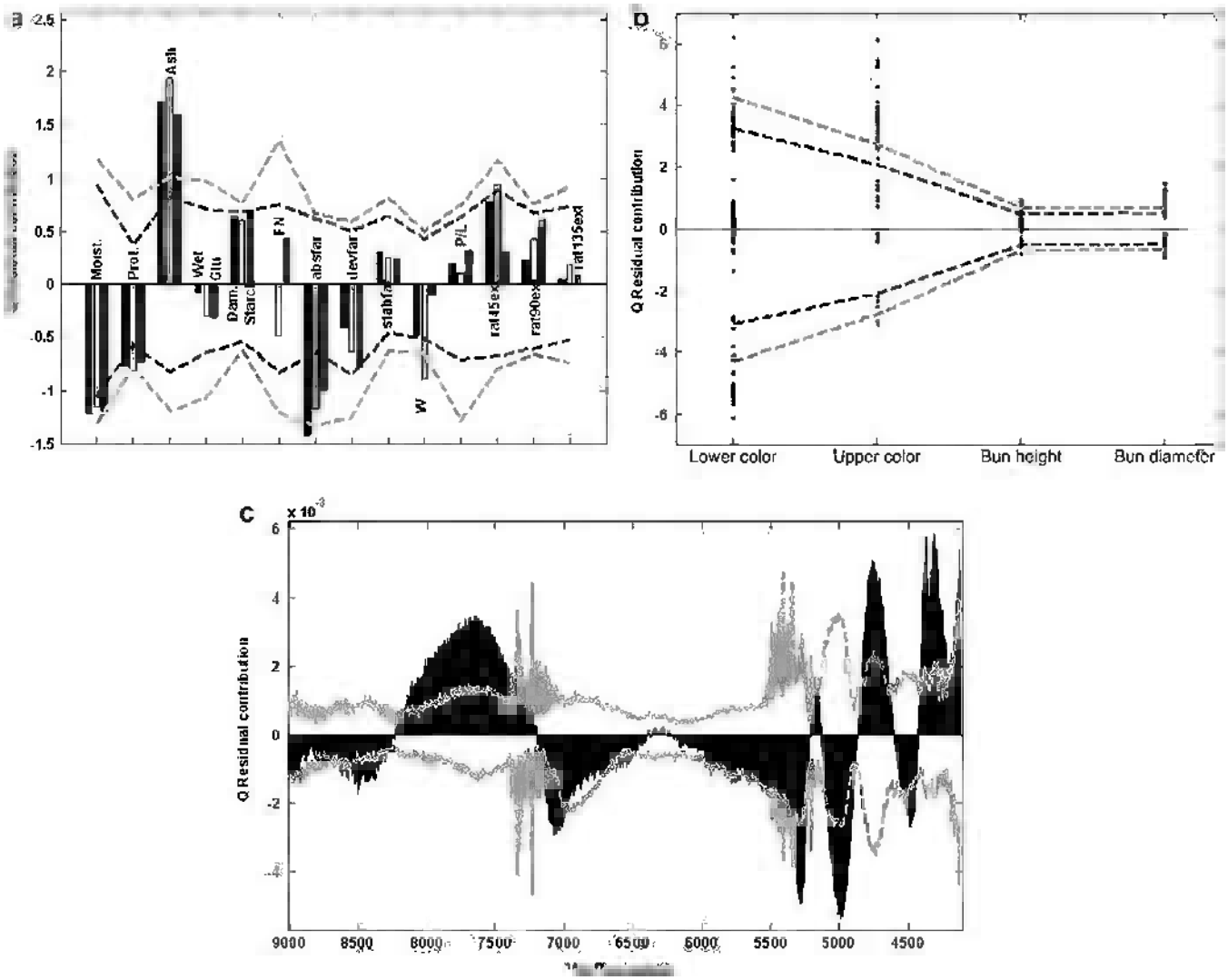

FIGURE 2.3
Contribution plots for selected flour batch samples. Contribution plots for batch no. 7, according to (a) rheoMCC (see Figure 2.1), (b) bread quality chart (see Figure 2.2), and (c) nirMCC (see Figure 2.4). Gray and black lines, 1st–99th and 5th–95th percentile confidence intervals, respectively.

able to record this modification and label as suspicious this batch because its acquisition has been done at a step that follows the arrival of flour at the bakery.

Also for the nirMCC chart, contribution plots can be used to individuate the spectral regions that mainly contribute to the high residuals shown by these samples. To complete the example, Figure 2.3c shows the contributions of the third delivery of batch 7, which result in higher than 95% percentile (I, III, and IV) and lower than 5% percentile (II) in the following regions:

I: 8200–7400 cm^{-1} (C–H second overtone and combination modes)
II: 5285 and 4990 cm^{-1} (C=O stretching second overtone)
III: 4760 cm^{-1} (O–H bending /C–O stretching combination)
IV: 4400–4250 cm^{-1} (starch and protein vibrational modes)

These contributions are commonly attributed to the starch and protein fractions (Shenk *et al.*, 2001). Although within the confidence limits for the contribution to *Q* residual in rheoMCC (see Figure 2.3a), damaged starch (index of starch quality, which increases as flour performance is reduced) had a high positive contribution for the samples of this batch. Regarding

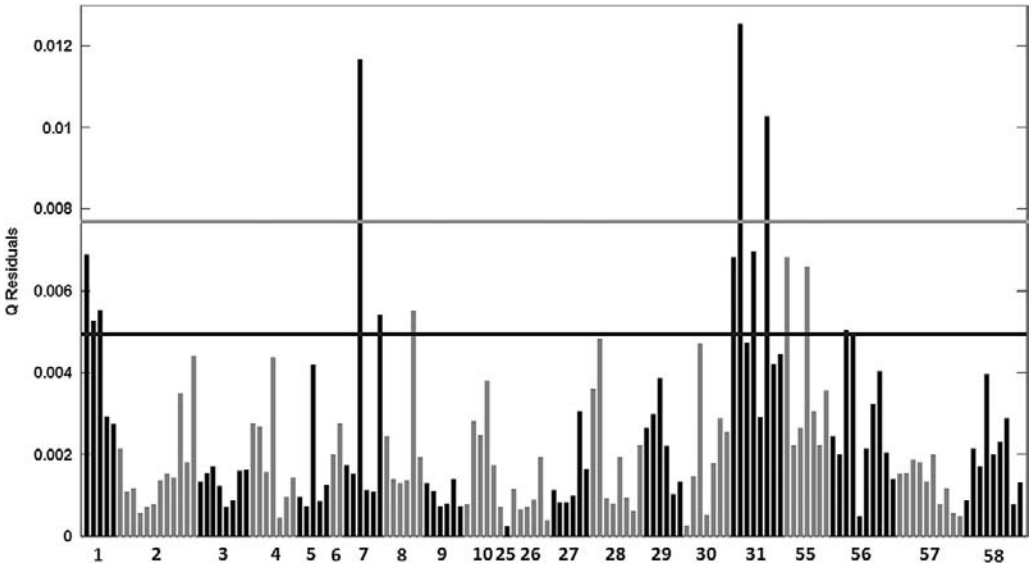

FIGURE 2.4
MCC based on NIR spectra of flour deliveries. PCA model for NIR spectra (two PCs, minimum RMSECV—CV method: leave-one-batch-out). *Q* distance is reported. Horizontal gray and black lines, Q_{crit} at 99% and 95% confidence limits, respectively. Flour batches are numbered progressively in order of employment; alternated black and gray colors are used for clarity.

proteins, the rheological contribution is coherent, referring to farinographic and alveographic properties that are related to protein quality.

EVALUATION OF PROTEIN PROFILE OF FLOUR BATCHES

The evaluation of the protein profile for wheat flour batches employed in production has been limited to the 11 batches identified in Table 2.1. The results of the analysis, reported in Li Vigni *et al.* (2010), show that the highest variability in terms of the protein subfractions content can be detected when considering flour batches from different years, which is in line with the well-known influence of the harvesting time and the crop history (e.g., weather conditions and agronomic treatments during its growth) on wheat protein content. However, the variability between subsequent deliveries of the same flour batch appears to be higher than expected, thus implying that the effect of the milling process is somehow relevant to the protein content differentiation of flour. In particular, some of the batches indicated as most problematic by the bakery, and presenting a production performance that falls above the confidence limits in the Q-Bake-based chart (see Figure 2.3), are characterized by a differentiation that generally corresponds to a higher content in gliadins, and lower content in glutenins, than the other, less problematic, batches. The balance of the two fractions, whose ratio for bread wheat should be close to 1 for genetic reasons, is important in determining gluten structure and, hence, its physical properties. A predominance of gliadin on the glutenin fraction generates a dough that has poor workability and non-optimal leavening properties: This situation is indicated by the gliadin-to-glutenin ratio, whose distribution for these batches is represented in Figure 2.5a, together with the HMW:LMW glutenins ratio (see Figure 2.5b). This ratio is generally reported as positively influencing dough strength, which increases when more of the HMW glutenins are present. The box and whisker representation offers an intuitive visualization of the distribution of the values for the considered flour batches; the gli:glu ratio intrabatch variability is manifest and similar for the 2 years of sampling, whereas the flour batches from 2009 show a ratio that is generally closer to 1 than do those from 2008. Batches with problems in production have either the highest gli:glu ratio in their year, such as batch 25, or several deliveries for which the ratio is significantly higher than 1 (batches 30, 31, and 57) and/or

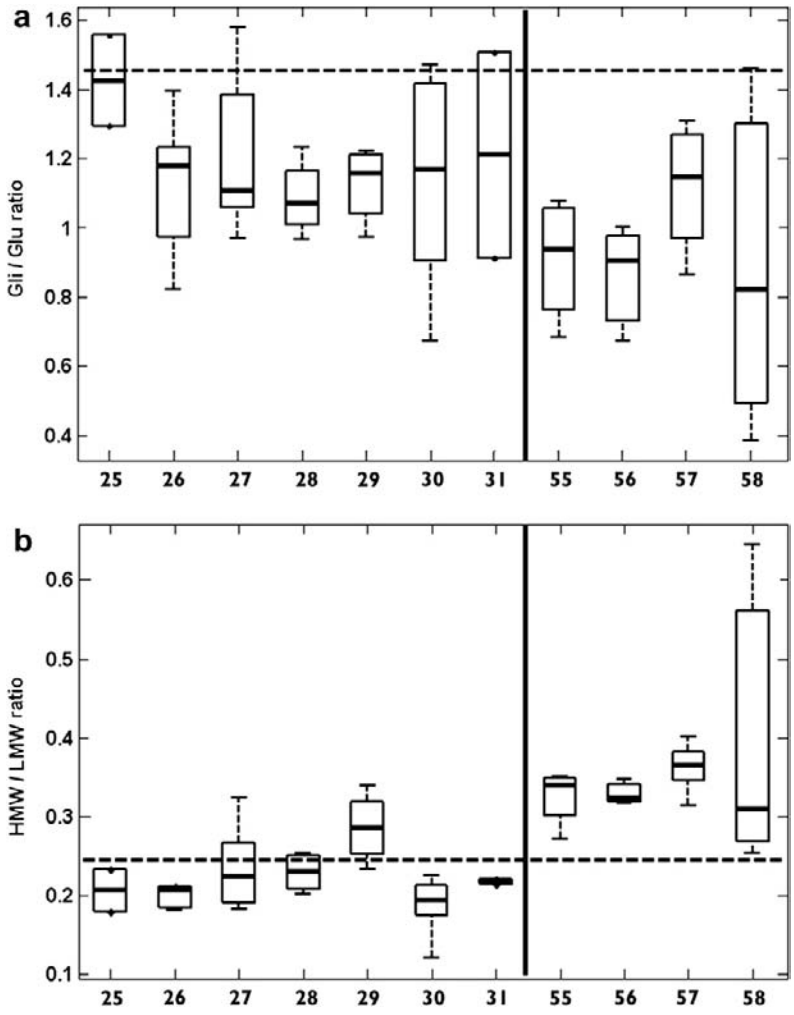

FIGURE 2.5
Box and whisker plot of protein ratios. The rectangle limits correspond to the 25th (lower) and 75th (upper) percentiles, and the internal line corresponds to the median. The dashed "whiskers" represent the total range of the values, if the extremes are not within the 50% variation. (a) Gliadin-to-glutenin ratio and (b) HMW-to-LMW glutenin subunits ratio for the 11 considered batches. Horizontal dotted lines represent the maximum (a) and the minimum (b) values indicatively reported in the literature for strong wheat flour. The vertical solid lines separate 2008 batches (left) from 2009 batches (right).

a great inner variability among different deliveries (batches 30, 31, and 58). Regarding the HMW:LMW ratio, strong bread wheat is reported to have values higher than 0.26, which indicates that almost all the samples from 2008 present a glutenin composition that indicates poor strength and performance of the flour, at least compared to samples from 2009, which have higher values for this ratio. A substantial similarity in median values can be found among the samples of the same year, although some batches have a higher variability range, such as batch 58 in 2009.

SUMMARY POINTS

- Multivariate evaluation of bread quality allows one to obtain a more compact and complete representation of production performance than considering univariate control charts for each property separately. Moreover, it allows a more realistic evaluation of product and departure from standards taking into account all different properties simultaneously.
- Evaluation of the rheological properties of incoming flour batches with an MCC approach helps in assessing the similarities and differences among new deliveries and historical data at a very preliminary step of the production chain so that rational planning of the best recipe to apply to exploit flour properties can be done at the beginning of production, instead of modifying it on the basis of the previous production outcome.

- NIR spectra can be easily and rapidly recorded on each delivery, and the information that can be obtained from nirMCC is generally similar to the rheoMCC findings, and often may also identify other sources of variability (e.g., storage and transfer).
- Characterization of protein composition allows the identification of the quantity and proportions of gluten components so that its quality can be assessed. Wheat flour batches that perform negatively in production mostly have a worse gluten quality, or a higher variability in terms of subfractions, which partially reflects on less stable rheological properties and causes more frequent changes in process conditions. Protein subfraction determination, however, is not suitable for routine analysis of flour batches; thus, the development of faster techniques, such as calibration models from NIR spectra, is desirable.

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