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Chapter 11
Wheat Quality

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Abstract Wheat quality is a complex concept whose importance lies in determining the ability of each segment of the post-harvest processing and marketing industries to minimize cost while maximizing profit. Wheat quality is also a highly subjective concept that could be defined differently by the various stakeholders in the wheat value chain. It is usually subdivided into milling, processing, end-use and nutritional quality. Of these subcomponents, end-use quality, the ability of a wheat variety to produce a specific food according to the consumers preferences is probably the most important. Wheat is used to make hundreds of different products worldwide, each one with specific grain quality requirements. In this chapter are explained the main traits that define end-use quality (grain hardness, gluten, color and starch) and that need to be modulated to obtain the desired product properties. The genetic control as well as the environmental effects on those traits are also presented. Finally, breeding and selection strategies to genetically improve end-use quality for the most important wheat products globally (bread, noodles, cookies, and pasta) are presented in brief.

Keywords Grain quality · Flour · Dough viscoelastic properties · Bread-making · Pasta-making · Glutenins · Molecular markers

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11.1 Learning Objectives

- To understand what wheat quality is and how to integrate it into breeding programs.

11.2 Introduction – What Is Wheat Quality?

George Bernard Shaw wrote: '*Take care to get what you like or you will be forced to like what you get*'. This aphorism probably summarizes the clearest vision of quality in the context of wheat improvement. The concept of wheat quality can be simple (edible versus inedible) or very complex (adaptation to explicit or implicit consumer demands). Although many methodologies have been designed to measure wheat quality, in reality most of them have been used to assess whether or not the grain of a cultivar can be adapted to a specific end-use. A modern wheat cultivar could be considered of high quality for the manufacture of standard bakery products; however, if we use this flour to make traditional products, our appreciation of this cultivar could be very different.

In the agri-food industry, many stakeholders are involved in the wheat value chain, from the farmer to the consumer. This means that the term quality can have different meanings depending on each of these stakeholders. For the farmer, a high-quality wheat cultivar might be the one that requires the lowest inputs, gives the highest grain yield and the grain can be sold at the highest price in the market. However, the miller will classify the cultivars according to the performance of the grain to produce flour (in a broad sense), along with the energy requirements for obtaining it. Finally, the baker will discriminate these materials for their utilization in each baking product.

At the opposite ends of the value chain, we find two very different stakeholders. The consumer defines quality using subjective parameters that are often difficult to analyze. At the other extreme, we find the wheat breeder who must work with objective data to design new wheat cultivars. These cultivars may be appreciated by the farmer, desired by the miller and valued by the baker, and we must also add the hope that they are to the taste of the consumer. However, the possibility of a uniform response from all of them is clearly unlikely. Probably, for a given cultivar, these various perspectives can range from positive to negative. Consequently, the Manichean vision between good and bad is clearly a mistake here. Once the desired product is chosen, the materials with high quality will be those that best perform for this product.

In this context, wheat grain components play an important role, together with their physico-chemical properties, in defining grain quality characteristics. There are three main components of wheat grain: proteins (7–18%), lipids (1.5–2%) and carbohydrates (60–75%), and other minor components such as vitamins and minerals. Proteins and carbohydrates, especially starch and arabinoxylans (the main component of wheat grain fiber), have notable influence on three grain characteristics

Fig. 11.1 Wheat products popular worldwide

closely linked to the technical wheat qualities required for diverse wheat products. These are the gluten viscoelastic properties, starch properties and grain hardness or texture, which are associated with milling, processing and end-use quality. There are other complementary parameters that sometimes have great importance such as flour or semolina yellow color.

11.3 Importance of Wheat Quality – Why We Need to Breed for It

Wheat, in contrast to other cereals, produces the greatest variety of consumer foods (Fig. 11.1). Each has unique attributes, which are often subtle in nature. The goal of delivering improved germplasm, i.e. ‘breeding for quality’, is to produce a genetic ‘package’ – a cultivar that possesses the greatest number of favorable alleles for grain and milling quality, processing and food manufacturing while importantly, aiming to meet the highest grade to obtain the best price for the grower. Most desirably, quality means the ability for each segment of the post-harvest processing and marketing industries to minimize cost while maximizing profit. This concept can be illustrated with a few examples: The ‘correct’ kernel hardness facilitates efficient milling that produces a flour of the ‘correct’ particle size and starch damage. The ‘correct’ glutenin profile produces doughs with the ‘correct’ mixing and rheological properties, and consumer traits such as product size and texture, and on and on.

Why are the cereal chemist and quality laboratory so integral to delivering improved wheat germplasm? Essentially it comes down to the fact that wheat cultivars do not last forever. Pests surmount resistances (see Chaps. 8, 9 and 19), farming practices evolve as do weather patterns creating new abiotic stresses (see Chap. 10), and the goal of attaining ever higher and more stable grain yields (see Chap. 21) necessitate the need to make crosses in the quest of seeking and combining 'better' alleles. As will be discussed in the Sect. 11.4, many of the main traits controlling quality are well characterized, and some are 'fixed' in breeding populations. Nevertheless, quality is the result of a large number of genes, too many to adequately select for by genotyping germplasm. In the never ending quest for better alleles, unwanted quality alleles will necessarily be introduced. For these reasons, delivering improved wheat germplasm will always involve some degree of empirical phenotyping for quality.

- **Exercise:** what is understood by *wheat quality* in your region/country? Are there any mechanisms to classify wheat grain based on its grain quality (grades, classes, etc.)? Is it grain quality a factor defining the grain price in the market?

11.4 Main Traits That Define Wheat Quality

11.4.1 Grain Hardness

Grain texture or hardness is the consequence of the degree of adhesion between the starch granules and the surrounding protein matrix inside the wheat endosperm. This trait has been used to classify wheat since antiquity, being the fundamental basis of differentiating the world trade of wheat grain. According to this trait, wheat is classified as very hard, hard or soft. Furthermore, this character is closely linked with the botanical classification of wheat: tetraploid wheat (subspecies of *Triticum turgidum* including durum wheat) exhibits very hard texture, whereas the *T. aestivum* group (hexaploid wheat including bread wheat) exhibits a texture that varies from hard to soft.

Grain hardness or texture is the single most important trait that determines end-use and technological utilization. It affects several parameters related to wheat milling: flour yield, energy requirement, particle size distribution of the flour and semolina, and percentage of starch damage (which strongly affects the dough water absorption linked with end-use quality). Due to differences in hardness, hard common wheat is used for bread-making while soft common wheat is preferred for cookies and pastries; very hard durum wheat is preferred for pasta. The very hard texture of durum wheat is associated with low flour yield and greater amounts of damaged starch in the flour. Durum flour is used in several Mediterranean regions to make traditional breads, which are usually denser than common wheat breads and have a more compact crumb texture. Durum wheat grain is primarily milled into semolina (larger particle size than flour) which is used to make pasta (made by extruding stiff semolina dough) or for couscous (made by agglomeration of semolina).

11.4.2 Gluten

In most cases, grain protein content varies between 7% and 18%. Of this protein, a large part (around 80%) is comprised of the proteins that form gluten. Gluten is the continuous protein viscoelastic network that develops when wheat flour is mechanically mixed with water. This protein network imparts to the wheat dough its unique properties which allow it to be processed into a wide range of products such as breads, noodles, pasta, cakes and biscuits. To give an example, in bread making gluten confers to the dough its viscoelasticity which allows the entrapment of carbon dioxide released by the yeast during leavening, whereas in pasta production it gives the necessary cohesiveness to extrude the dough and to form the desired shape. Products such as noodles, flatbreads and some cookies that need a sheeting procedure in their manufacture require flours with good extensibility to perform well in these processes.

The large complex polymer known as gluten is primarily comprised of two type of proteins: the monomeric gliadins (single-chain polypeptides), and the polymeric glutenins (multiple polypeptide chains linked by disulfide bonds), which can be separated based on their solubility in aqueous alcohols and acid solutions and alkali, respectively. Gliadins, which account for around 60% of the gluten, are classified into ω-gliadins, α/β-gliadins and γ-gliadins and contribute mainly to the viscosity and extensibility by working as plasticizers of the dough. Glutenins, which are subdivided into high molecular weight glutenins (HMW-Gs) and low molecular weight glutenins (LMW-Gs), are aggregating proteins with cysteine groups at the end and in the middle of the protein sequence. These cysteines enable intermolecular disulfide bonds, creating a large range in molecular weight. Glutenins are more responsible for the cohesive and elastic properties of the dough. All these gluten components show tremendous variation in the wheat germplasm pool leading to different gluten structures with contrasting properties and impact on dough physical and physicochemical properties. These dough properties are also highly modulated by the protein or gluten content of the flour. Each type of these gluten networks with specific properties is more suitable to produce a specific type of wheat product. For all common wheat products certain levels of dough extensibility are necessary whereas dough strength requirements vary depending on the product: pan bread, strong gluten; hearth and flat breads and noodles, medium to strong gluten; and cookies and cakes, weak gluten. High quality pasta is made with durum with a high level of strong and tenacious gluten.

11.4.3 Color

Flour color plays a significant role in the end-use quality of wheat, particularly for Asian noodles, steamed bread and pasta since it affects consumer acceptance, market value and human nutrition (see Chap. 12). Color has two essential components:

inherent capacity to produce pigments (for example, presence of carotenoids or liberated flavonoids for alkaline noodles), and the capacity to not degrade those colors during processing. Desirable yellow color for 'white' salted noodles may range from very low (no yellow is preferred) to creamy yellow. For alkaline noodles, the pH-induced yellow color is appreciated and quite often, higher is better. For durum semolina, a high yellow color is desired. The color of the grain and the end-products derived, depends on genetic, environmental and processing factors. Genes coding for enzymes involved in pigment accumulation and degradation affect color. The main pigments are carotenoids (yellow pigment) and anthocyanins (responsible for blue to red grain), both are important for their aesthetic role and have been shown to benefit ocular health. Modern durum varieties and bread wheats have higher and lower yellow pigment, respectively, than older wheat varieties due to breeding selection. In durum wheat grains, the major carotenoid is the xanthophyll lutein, mostly located in the endosperm and consequently found in the flour/semolina. However, during flour processing, carotenoid degradation can occur by oxidases such as the lipoxygenases (LOX) and the polyphenol oxidase enzymes that can generate brown polymers that can mask the yellow color of pasta or make noodles appear dull. Fortunately, high yellow pigment levels work against LOX activity. Keeping the bran level in flour to a minimum is a good way to reduce these oxidative enzyme levels. Individual pigments can be measured using HPLC. Colorimetric methods such as NIR, extraction of yellow pigments or light reflectance using a Minolta CR-300 Chroma Meter of flour/semolina to measure lightness, red-green and yellow-blue chromaticity (CIE 1986) coordinates are fast and non-destructive.

11.4.4 Starch

Starch is the main component of wheat grain representing about 70% of the total dry matter, and is comprised of two polymers based on D-glucose residues: one linear formed by α-(1,4) residues (amylose) that represents 22–35% and the other (amylopectin) with α-(1,4) residues ramified each 20–30 residues by α-(1,6) linkages representing 65–78%. These polymers are synthesized in the amyloplast by two different synthetic routes; the search for cultivars with modifications of the enzymes involved in starch synthesis has been key to the generation of novel starches with special properties due to changes in the amylose/amylopectin ratio. The relationship between both polymers can affect the physical and chemical properties of starch (gelatinization, pasting and gelation), and consequently the quality of the end-products.

Starch properties greatly influence food products made from wheat flour or semolina, especially Asian noodles where low amylose content is desirable to obtain the desired texture. In addition to the quality of noodles, starch is associated with the shelf life of pre-cooked products and the nutritional value: a higher amylose content is associated with higher resistant starch content (functioning as fiber), which is associated with health (low glycemic index and better gut health), although with lower end-use quality too.

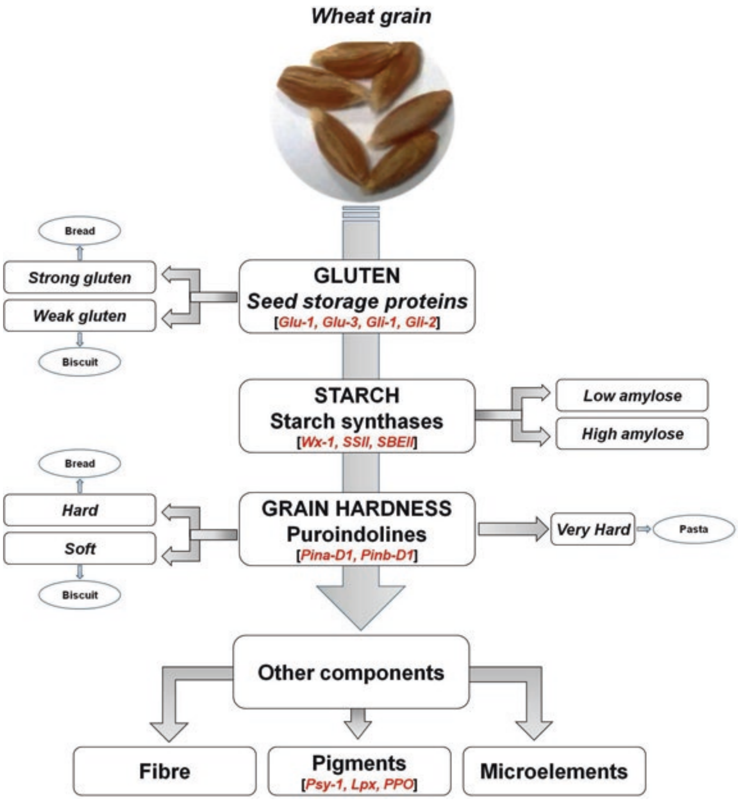

Fig. 11.2 Main grain components, traits and genes associated to wheat quality

11.5 Genetic Control of the Quality Traits and Environmental Effects

Genetic improvement is at the basis of crop breeding. For this reason, knowing the heritability of each quality trait, its genetic basis and how much of their variation is influenced by different environmental factors, is of fundamental importance for an effective improvement of wheat quality. Among the elements that influence wheat quality, grain hardness, gluten quality, flour color and starch properties have been the most studied. For this reason, extensive information is available on the genetic (Fig. 11.2 and Table 11.1) and environmental factors affecting their variation.

Specifically, variation in grain hardness is mainly determined by the *Puroindoline a* (*Pina-D1*) and *Puroindoline b* (*Pinb-D1*) genes, located at the *Hardness* locus, on the short arm of chromosome 5D. When the wild-type form of the two *Pin* genes is present (alleles *Pina-D1a* and *Pinb-D1a*), wheat kernels exhibit a soft texture. In contrast, when either of the two genes is mutated, wheat kernels exhibit a hard texture. Due to the lack of the D genome and hence the two *Pin-D1* genes, durum

Table 11.1 Genes associated with major influences on wheat quality traits

Trait	Chromosomes	Locus/gene	Protein/enzyme
Grain hardness	5DS	*Hardness*	Puroindoline a, b
Gluten quality	1AS, 1BS, 1DS	*Glu3*	Low-molecular-weight glutenins
	1AL, 1BL, 1DL	*Glu1*	High-molecular-weight glutenins
	1AS, 1BS, 1DS	*Gli1*	γ and ω-gliadins
	6AL, 6BL, 6DL	*Gli2*	α/β-gliadins
Yellow pigment accumulation	7AL, 7BL, 7DL	*Psy1*	Phytoene synthase
	4AL, 4BL, 4DL	*Pds1*	Phytoene desaturase
	2AS, 2BS, 2DS	*Zds1*	ζ-carotene desaturase
	3A, 3B, 3D	*ε-LCY*	Lycopene ε-cyclase
Yellow pigment degradation	4AS, 4BS, 4DS	*Lox1.1*	Lipoxygenase
Flour discoloration	2AL, 2BL, 2DL	*Ppo1*	Polyphenol oxidase
Starch functionality	7AS, 4AL, 7DS	*Wx1*	Granule bound starch synthase I
	7AS, 7BS, 7DS	*Ss1*	Starch synthase I
	7AS, 7BS, 7DS	*Ss2*	Starch synthase IIa
	1AS, 1BS, 1DS	*Ss3*	Starch synthase III
	7AL, 7BL, 7DL	*SbeI*	Starch branching enzyme I
	2AL, 2BL, 2DL	*SbeIIa*	Starch branching enzyme IIa
	2AL, 2BL, 2DL	*SbeIIb*	Starch branching enzyme IIb

wheat kernels exhibit an extremely hard texture. Additional minor variation in kernel hardness among wheat varieties with the same *Pin* profile have also been identified. This variation could be determined by both environmental and genetic factors affecting, among the others, grain protein and moisture content, grain vitreousness and morphology, and pentosan quantity and quality.

Differently, moderate to high heritability has been observed for gluten quality with, on average, 60% of its variation being explained by differences in the genotype. Most of this variation is related to differences in the combination of the gluten-forming proteins, with the HMW-Gs (*Glu-1* loci, long arm of the group 1 chromosomes) and the LMW-Gs (*Glu-3* loci, short arm of the group 1 chromosomes) being typically the major determinants of these differences. Specifically, variation in the HMW-Gs has been shown to explain from 20% to 30% of the variation in gluten strength in common wheat and, among the *Glu-1* loci, the *Glu-D1* locus has typically a greater effect on gluten quality, followed by the *Glu-B1* and the *Glu-A1* loci, respectively. Wide allelic variation has been detected at each *Glu-1* locus and alleles associated with specific gluten characteristics have been identified. The effect of the LMW-Gs on gluten quality is different in common and durum wheat. In common wheat, variation in the LMW-Gs has typically a lower impact on gluten properties compared to the HMW-Gs, accounting for 10–20% of the observed variation. Differently, in durum wheat, the effect of the LMW-Gs on gluten quality is greater compared to the HMW-Gs. In both cases, alleles associated with variation in gluten strength have been identified. Besides the genetic factors, several studies have shown that the environment plays a significant role in determining gluten quality, influencing from 3% to 50% of its variation. Depending on the environment, the content and ratio of the gluten-forming proteins change greatly, thus affecting both the rheological and end-use quality. For example, drought stress is typically associated with an increase in grain protein content and in the gluten polymeric fraction which results in an increase in gluten strength and tenacity. In contrast, wheat lines grown under heat stress typically have a greater protein content but lower glutenin/gliadin ratio, resulting in a weaker and more extensible gluten. However, the response depends on when the heat stress occurs during grain development and its severity and duration.

Similar to kernel hardness, flour or semolina color typically exhibits high heritability. Indeed, ~90% of the variation observed in flour or semolina yellowness depends on the genotype. Even though all the genes and their relative allelic variants involved in the modulation of flour yellowness have not been identified, variation in the *Phytoene synthase I* (*PsyI*) genes have been associated in both common and durum wheat with major changes in flour and semolina carotenoid content, typically explaining >20% of the observed phenotypic variation. Additional smaller variation of this trait is influenced by the environment, which could affect both the expression level of the different enzymes involved in the synthesis of the yellow pigments, both the concentration of the pigments in the grain (the smaller the grain, the higher the concentration).

Major changes in flour color may result from the activity of specific enzymes, which are also highly genetically controlled. For example, degradation of the yellow color is mainly determined by the activity of LOX. Genes encoding this enzyme have been mapped and the alleles *Lox-B1.1c* and *TaLox-B1b* in durum and common wheat, respectively, have been associated with drastic reductions in LOX quantity and activity. Similarly, genes encoding polyphenol oxidase (PPO), which is associated with the undesirable discoloration of some wheat products have been identified and mapped. Among them, variation in the *Ppo-A1* and *Ppo-D1* genes have been associated with major variations in the activity of this enzyme with the alleles *Ppo-A1b* and *Ppo-D1a* being associated with lower PPO activity.

Like gluten quality, starch pasting properties exhibit moderate to high heritability and differences in the genotype have been shown to consistently explain more than 30% of the observed phenotypic variation. Mutations in key genes involved in the starch biosynthetic pathway have been associated with significant changes in starch physical properties. Specifically, mutations in the gene involved in amylose synthesis (Granule-bound starch synthase, GBSS, or waxy protein; *Wx-1* loci) have been associated with the synthesis of starch with either a higher proportion of amylopectin or with the complete absence of amylose (waxy starch). Similarly, mutations in the genes involved in the synthesis of amylopectin, like the Starch synthase (SS) or the Starch branching enzyme (SBE) genes, led to the synthesis of starch with greater amylose content (resistant starch). However, up to ~60% of the observed starch physical properties are also influenced by environmental conditions and variation in other grain components. Biotic and abiotic stresses during plant growth are associated with changes in the starch properties. For example, lodging is often associated with increased alpha amylase activity, which leads to more rapidly degraded starch in flour during mixing and fermentation causing different problems in the end-use quality of the products.

11.6 Breeding for Quality

11.6.1 Integrating Quality in the Breeding Process

Wheat breeding programs measure a range of plant and grain characteristics to improve grain yield, abiotic and biotic resistance, adaptation and grain quality suitable for markets (see Chaps. 5, 6 and 7). Integrating quality into the breeding process, although different between programs, has common features. Breeding programs make many crosses between parents possessing a value-added trait(s), which results in the creation of large populations to evaluate in the generation cycle. Therefore high-throughput, small-scale tests that allow discrimination between acceptable and unacceptable/borderline samples can help reduce the size of the material carried forward. Later generations (replicated field trials) produce more grain of fewer samples, which is amenable for conducting more time consuming and accurate tests.

11.6.2 Bread

Bread is probably one of the most universal foods and there is a huge diversity of types worldwide (pan, hearth, flat, steam breads, etc.). There are differences in specific grain quality requirements, processing conditions, and end-product properties for each type of bread (Fig. 11.3). All breads are made from viscoelastic and cohesive doughs prepared from refined or whole-meal flour. They are mostly produced from hard common wheat flour, but durum flour or semolina is also used in some areas to make bread. Due to the huge diversity of breads and contrasting consumer preferences, it is difficult to define what makes a good bread but in most of the cases, bread quality is related to the crust and crumb properties, color and other organoleptic and more subjective properties such as texture, aroma and taste.

In breeding, emphasis has been put in improving those traits related with the volume, texture and color of bread. Bread ('loaf') volume is a crucial trait for pan bread and certain types of hearth breads and depends highly on dough strength and extensibility. During the fermentation stage in bread-making, doughs with sufficient gluten strength will have cells with the capacity to retain the gases without collapsing. If the same dough has also high extensibility, those cells will enlarge giving the bread the desired large volume. Those same dough or gluten characteristics are also important to obtain a uniform, fine and silky crumb, which is desirable for pan breads (less important in hearth breads or flat breads). Crumb with light white color

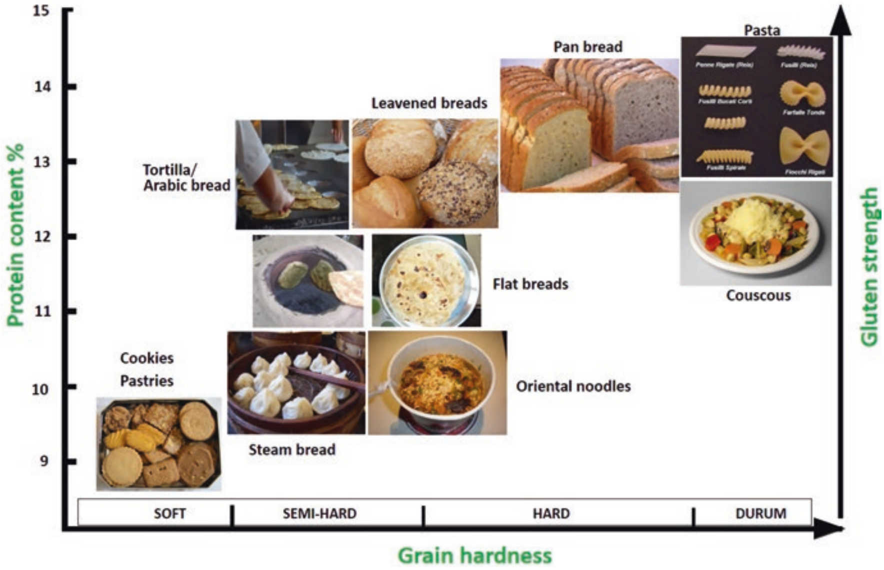

Fig. 11.3 General grain quality characteristics of wheat products

is a characteristic desired by most consumers, and thus 'whiteness' has been targeted by breeding programs, selecting germplasm with reduced or almost null amount of pigments.

Phenotyping for bread-making quality is not easy. For bread and any other wheat product, manufacturing that product (with laboratory scale methods or in full scale) should be the critical and ultimate test to define the suitability of a wheat cultivar to produce that product. Several small-scale bread-making protocols are available and are used routinely in wheat quality labs depending on capability. However, it is not always possible to perform such tests due to insufficient grain, high cost and time required to do the analysis, etc. Consequently, tests to evaluate traits related to or predictive of bread-making are usually applied (Table 11.2). Flour color is measured with a Minolta color meter or similar instrument.

11.6.3 Noodles

Here we delineate *noodles* from pasta. Although both may resemble strands of dough prepared from wheat flour, which are then boiled prior to consumption, noodles are most commonly prepared from common wheat by sheeting and cutting, whereas pasta is extruded and is made from durum wheat semolina. Most noodles are simple in composition: flour, water and salt. The key first difference among noodle types is, What kind of salt? Two approaches are encountered: normal table salt, sodium chloride at 1–5% on a flour weight basis (flour representing 100%), the

Table 11.2 Common wheat quality tests/machines used globally to determine quality traits

Test	N° of samples[a] per day	Grain/flour required (g)	Traits analyzed
NIRS	150–300	20–40	Moisture, hardness, protein, color
PPO Activity[b]	60	0.1	PPO activity
SDS-Sedimentation	100	0.5–2	Overall gluten quality
Solvent Retention Capacity	25[c]	20	Damaged starch, overall gluten quality, arabinoxylans, gliadin
Glutomatic	30	10	Gluten content and gluten strength
Mixograph	35	10, 35	Optimum mixing time, gluten strength
Alveograph	14	250	Gluten strength and extensibility
Farinograph	7	10, 50, 300	Water absorption, dough development time, softening and stability
Extensograph	12	300	Dough extensibility and strength
Falling number	70	6–7.5	Detecting sprouting damage
Rapid Visco Analyzer	28	3–4	Starch pasting viscosities

[a]Number of samples analyzed per day by one experienced technician working for eight hours
[b]L-DOPA whole kernel assay
[c]Performed with four solvents

second is a mixture of alkaline salts termed kansui. Kansui is often equal amounts of potassium and sodium carbonate (e.g. 0.5% each), less frequently sodium hydroxide. The use of kansui lends its name to the second type of noodle based on formula, ‘alkaline noodles’. In addition to kansui, alkaline noodles will often have 1–1.5% NaCl.

After the basic formulation, processing dictates the next delineation. Classifications include fresh, dried, boiled (usually parboiled) and frozen. A unique style of noodle that has grown tremendously in popularity is the ‘instant noodle’. Instant noodles, as the name implies, are quick-cooking due to the fact that they are essentially already cooked. Processing involves steaming and (usually) frying. For the consumer, ‘cooking’ is really simply rehydrating. Raw fresh noodles are termed Chinese raw noodles and Japanese Udon noodles, both are styles of ‘white salted’ noodles. Similarly, raw alkaline noodles may be ‘Cantonese’ in Southeast Asia or ‘Chukamen’ in Japan. White salted noodles are often dried to extend shelf life. Parboiled alkaline noodles are consumed throughout Southeast Asia (‘hokkien’) and Taiwan (‘wet noodles’).

Although the variety of noodle types and processing techniques is great, the fundamental basis for quality lies with the flour itself. From a consumer standpoint, most of the concern is with color and texture. Desirable yellow color for ‘white’ salted noodles may range from very low (white is preferred) to creamy yellow. For alkaline noodles, the pH-induced yellow color is appreciated and quite often, higher is better. Discoloration is primarily the result of PPO, but not entirely. For screening germplasm, color is conveniently measured on flour or raw noodle sheets using a Minolta color meter or similar instrument. Resting raw noodle sheets for 24 h at room temperature can be used to determine undesirable darkening, ΔL*. A highly efficient system of screening germplasm for PPO activity uses L-DOPA (L-3,4-dihydroxyphenylalanine) as a substrate on five intact kernels.

After appearance, texture is next in importance. Texture is a complex trait to measure, but descriptive adjectives include firmness, springiness, stickiness, and gumminess. The surface character of the noodle (smoothness) is also important. Texture is assessed using either trained sensory panelists or instrumental approaches, for example the TA-XTPlus C. The primary genetic determinants of texture are starch and glutenin composition. Starch composition is relatively simple, in that either a 'normal' ratio of amylose to amylopectin is preferred as it conveys a firmer texture ('bite'), or a reduced amylose, 'partial waxy' genotype is preferred. Partial waxy wheats are produced by selecting a null allele at one of the *Wx-1* genes, usually on chromosome 4A (*Wx-B1)*. Partial waxy germplasm can be selected using DNA markers or empirically using the Flour Swelling Volume test or pasting viscometers such as the RapidVisco Analyzer or MicroAmylograph. Partial waxy varieties are preferred for Udon noodles. The role of glutenins is more complex, but can be viewed from the standpoint of dough rheology or simply the assessment of texture using sensory or instrumental analysis. The big caveat on texture is the role that protein content plays, mostly independent of glutenin haplotype.

11.6.4 Cookies

A large proportion of soft wheats are used to make cookies and cakes. The foremost genetic consideration from a quality standpoint is *soft kernel texture*, which is conditioned by the puroindoline genes/proteins.

Although a number of flour analyses can be performed to predict consumer end-product quality, such as the Solvent Retention Capacity tests, quite often laboratory bake tests are employed. Two common tests involve baking 'sugar-snap' cookies, which represent low moisture soft wheat products, and cakes, which represent high moisture, batter-based products. At the USDA Western Wheat Quality Lab, Japanese sponge cakes provide objective information for selecting superior soft wheat germplasm. As noted above, the variety of wheat foods is too numerous to characterize individually. Thus, these two 'model systems' provide sufficient prediction of consumer products to guide breeding programs.

11.6.5 Pasta

Durum wheat breeders consider a range of quality specifications before releasing a new variety (Table 11.3) but only measure a few in the early stages of the breeding cycle due to resource limitations caused by large numbers of samples to be

Table 11.3 Quality traits of different durum wheat samples

Traits/sample	A	B	C	D	E	F
Protein (%)	11.0	13.0	15.5	12.5	10.0	13.0
Test weight (kg/hl)	79.0	79.0	78.0	82.0	72.5	78.5
Falling number	389	200	600	650	720	500
Screenings	3.2	4.1	8.1	3.2	1.9	2.5

The acceptable samples are D and F with A having low protein (required >12%), B low FN (required >250 s), C high screenings and E low TW (required >76 kg/hL) and protein

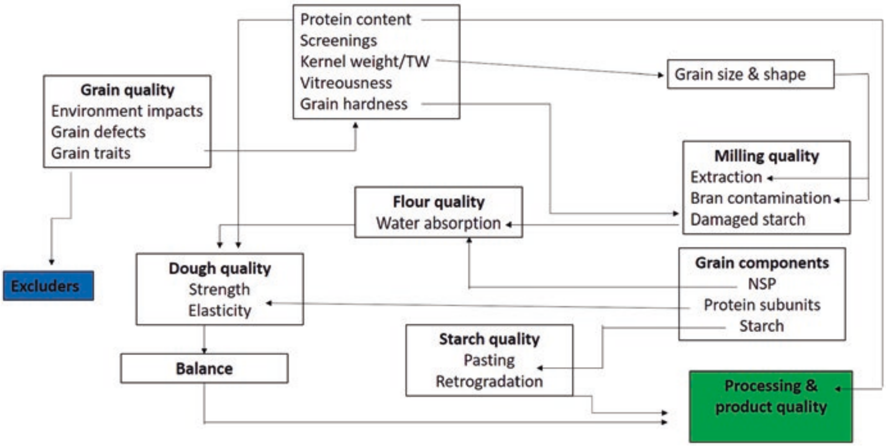

Fig. 11.4 Interactions defining pasta-making quality

evaluated. Key measures are grain protein and weight, screenings, some indicator of dough strength and color of wholemeal or semolina (Table 11.3). To understand the interactions leading to pasta quality refer to Fig. 11.4. Grain quality can be affected by (1) environmental impacts on the grain that negatively affect processing and the breeder avoids testing such grain: blackpoint (10% limit), fungal staining, frosted, white grain, heat and insect damaged grain; (2) grain defects: test weight <76 kg/hl impacts milling yield; falling number <250 s impacts pasta appearance and cooking loss; screenings >5% reduces milling yield; low vitreosity kernels tends to produce more flour on milling and creates poor pasta strength, such defects can result in exclusion from testing by the breeder; (3) grain traits: key traits to ensure good pasta quality are grain protein >12–13%, highly vitreous (>70%), hard, large and sound grain (thousand kernel weight >35 g; test weight >76 kg/hl) and acceptable glutenin allelic composition which impacts gluten strength. Generally, if these minimum standards are met, such grain when milled produces particles with the correct size distribution, with minimal bran in good yield and when mixed with water, creates dough that absorbs water uniformly. This dough when extruded or sheeted makes pasta with a good gluten matrix surrounding the starch granules which ensures good texture after cooking. Of course, all these measures depend on the genotype being tested and the interaction with the environment.

High-throughput tests that are inexpensive are desired by cereal chemists in a breeding program (Table 11.2). Near infrared spectroscopy (NIRS) is probably the best known instrument using either manufacturer supplied in-built or in-house developed calibrations. This technology allows non-destructive assessment of grain samples (35–150 g) at about 0.2–2 min/sample and can be automated. NIRS predictions for protein, moisture, wet gluten, test weight, yellow pigment, hardness and ash are being used by breeders. A more recent tool is image analysis to measure grain vitreousness, semolina speck counts and blackpoint but has yet to find wide application in breeding programs. Color assessment is performed rapidly on wholemeal or semolina using a colorimeter to measure yellowness (b*). Most small scale tests useful to a breeding program tend to focus on measures of dough quality (SDS sedimentation, mixograph, gluten index, glutopeak) requiring 1–10 g. Instrumental and cooking tests to evaluate dried pasta do not require large amounts of sample and there are standardized international methods available. There is also no standard method to prepare laboratory scale pasta.

- **Exercise:** choose one important wheat product of your region and identify what are the main quality traits that define its end-use quality and what grain components affect it. Assess how local breeding programs integrate quality into their breeding schemes to ensure high end-use quality of this product.

11.6.6 Molecular Markers Useful to Select for the Above-Mentioned Traits

As reported in the previous sections, several high-throughput, small-scale and highly repeatable tests have been developed in order to accurately and efficiently define the quality of a specific wheat line. However, even if phenotypic characterization will always be needed due to the inherent complexity of quality traits, the use of molecular markers (here intended as PCR-based molecular markers) and other genotyping tools could greatly improve the efficiency and speed of wheat quality selection.

Up to now, several molecular markers targeting the genes associated with major quality traits such as kernel hardness, gluten quality, flour or semolina color and discoloration, and starch quality are available and are routinely used by most wheat breeding programs. However, in most of the cases, the available molecular markers are only targeting a subset of all the genes contributing to a specific quality trait and are often discriminative for only few of the alleles detected for each gene. For this reason, in the context of wheat quality, molecular markers should be preferably used to introgress or detect the presence of specific allelic variants associated with a trait of interest, rather than to predict the overall quality profile of a specific wheat line.

In contrast, genomic selection (GS) has arisen as a promising tool for the prediction of wheat quality. Using genomic selection, most of the wheat quality traits could be predicted with an accuracy ranging from ~60% for traits like gluten strength, to ~40% for traits more highly influenced by the environment such as protein content and dough extensibility. In contrast to single-locus molecular markers, genomic selection can capture the genetic complexity of the different quality traits at once, thus making the selection process more efficient and accurate. However, it is important to take into consideration that the accuracy of GS is highly affected, among the others, by the size of the training population, its relationship with the testing population and the quality of the phenotypic data. For these reasons, the application of GS to wheat quality prediction is likely to be restricted to those breeding programs that have the necessary resources to develop reliable prediction models.

11.7 Key Concepts

Grain quality is a complex and diverse concept that is mainly defined by the end-product. There is no wheat with bad or good quality; there is wheat with the correct quality to elaborate a given product or there is wheat with undesirable quality to make another product(s).

11.8 Conclusions

Grain quality is important as it defines the end-use of wheat and contributes to maximize profit across the wheat value chain. It adds value to the rest of breeding activities as it is a key set of characteristics for the trading and commercialization of the grain. Grain quality should be an integral part of the breeding process and considered within the variety development process. This is a highly feasible objective due to the knowledge acquired about the genetic control of several quality traits, which is in overall high, making genetic improvement approaches possible. Grain yield and quality are not confronted and can be obtained at the same time if the right breeding and selection strategies are implemented.

Further Reading

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