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SECOND CYCLE DEPARTMENT

COURSE HANDOUT

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CEREAL INDUSTRY TECHNOLOGY

Intended for

Bachelor's and master's students specializing in agri-food technology

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Abreviations list

AGEs: Advanced Glycation End-Products
AC : Amylose content
AX : Arabinoxylans
BU : Brabender unit
CAP : Common agricultural policy
CD : Celiac disease
DM : Dry matter
DF : dietary fiber
DNA : Deoxyribonucleic acid
DPPH : 2,2-diphenyl1-picrylhydrazyl
EU: European Union
FAO : Food and Agriculture Organization
FA : Ferulic Acid
GC : Gel consistency
GFD: Gluten free diet
GMP : Glutenin macropolymer
GT : Gelatinization temperature
HMW : High molecular weight
LMW-GS : Low molecular weight glutenin sub units
MW: Molecular weight
N: Nitrogen
NIRS : Near infrared spectroscopy
NSP: Nonstarch Polysaccharides
QPM: Quality protein maize
ORAC : Oxygen radical absorbance capacity
PAT : Phosphinothricin acetyltransferase
PPO : Protoporphyrinogen
RVA: Rapid Visco Analyser
S: Sulfur
SAAT : Sonication Assisted Agrobacterium mediated transformation
SBE : Starch branching enzyme
SDS : Safety Data Sheets
SmF : Submerged fermentation
SSF : Solid state fermentation
TDF : Total dietary fiber
TKW : Thousand kernel weight
UAA: Utilisable agricultural area
UNESCO : United Nations Educational, Scientific and Cultural Organization
UV: Ultraviolet
WF : Wheat flour
WUAX: Water-unextractable fraction

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Preamble

This handout is specifically dedicated to 4th year Food Science and Technology students from higher education schools in agronomic sciences, but also for other agronomy courses at the university, biology and food sciences (license and Matser).

The handout reviews the major cereal species, starting with wheat. It goes on to discuss other major species such as rice and maize. Each chapter reviews grain structure, chemical composition (including carbohydrate and protein content), processing and applications in food and beverage products. Cereal grains for the food and beverage industries are an essential reference for academic researchers interested in the area of cereal grains and products. It is also an invaluable reference for professionals in the food and beverage industry working with cereal products, including ingredient manufacturers, food technologists, nutritionists, as well aspolicy-makers and health care professionals.

This course handout of ″ Cereal industry technology ″ is structured in four parts such as:

- The 1st chapter concerns the cereal grains
- The 2nd chapter deals the wheat and the other *Triticum* grains

This course includes practical work which is actually carried out in the form of educational outings on practical sites such as the visit of flour mill and a semolina factory

Preliminary Concept

Cereals are recognized to be edible seeds or grains of the Poaceae family [1]. Among the grains, rye, oats, barley, maize, triticale, and millet are grown in numerous countries. With almost half of all grain production coming from rice and wheat, these two plants are the most prevalent in the world. All cereals have an endosperm that is packed with starch grains and an embryo, which is the genetic material for another plant. Grain varieties can be found worldwide, and environmental and genetic factors affect how they are produced. Because their seeds are so nutrient-dense, cereals are called grains.

Some grains have been consumed by both humans and animals as staple foods since the beginning of civilization. The most important sources of nutrition are cereals, which offer substantial amounts of protein calories, B vitamins, and minerals in meals. They are often cheap to cultivate, transport, and store, and when kept dry, they don't disintegrate easily [1]. Although numerous cereals have different architectures, there are some basic characteristics that all grains share. A structure with narrow walls that contains the developing plant could be the germ (or growing life). As the seed is being formed, the scutellum separates the endosperm from the rest of the grain in order to prepare the nutrient stores. The endosperm is composed of thin-walled, starch-led cells. In the unlikely event that the grain sprouts, the seedling uses nutrients augmented by endosperm until the greenness improves and photosynthesis begins [2]

Cereals are a vital component of diets and significantly increase human nutrient intake. Energy, protein, dietary fiber, vitamins, minerals, and phytochemicals are all abundant in them. Cereals are susceptible to fungal infections, which can cause adulteration and the production of mycotoxins during storage. These infections are particularly dangerous to human health since they are difficult to detect in cereal and cereal products. To guarantee food safety and quality, it is crucial to screen and evaluate cereal foods' safety and quality qualities [1].

Selecting technology is crucial and ought to be based on the nation's interests and limitations (its development plan, integration into the regional and international economy, equipment modification for local products, and processing methods that preserve their nutritional value) [2].

Dietary fiber's impact on health and illness, particularly diabetes, heart disease, intestinal health, and some cancers, has received a lot of research throughout the past three decades. The food industry began to create foods high in fiber and reintroduce fiber to refined foods as a result. Because whole grain contains more bioactive components and micronutrients than diets enriched with fibers that have been acquired or produced through enzyme treatment, heat processing, or chemical processing, scientists have proposed that whole grain foods are superior [3].

Interest in separating the micronutrient-rich aleurone fiber fraction from wheat was sparked by this. The inner site of the bran contains a single cell layer called aleurone. The majority of the wheat grain's nutrients, vitamins, phenolic antioxidants, and lignans are present in it. Aleurone cells can now be fully separated from the other layers of wheat bran thanks to innovative milling and dry-fractionation techniques. This results in a fiber-rich concentrate that may contain many of the "whole grain kernel bioactives," which have recently been used in a number of studies [3].

The actual technological processing of any food product may typically have the biggest influence on its quality. Different iterations of the traditional procedure are used today, although in the past the processes were consistent and binding [3]. With improved raw material dry matter valuation, modern processes are typically faster and more efficient. The goal is to achieve high quality and standardization of final food products by reducing waste and increasing automation and computer control. Protecting their unique production techniques gives manufacturing companies a competitive advantage and increases product sales [3].

The continual structural changes require regular response. This mostly relates to the growth of bakery product production, the establishment of bakeries within supermarkets, and the industrial manufacturing of foods that are ready to cook or oven-ready. The production of dietetic and functional meals is an area that is expanding quickly, which has an impact on the use of various cereals in human nutrition as well as the potential growth of the mill sector. Customized flour is made in accordance with the needs of the consumer. Additionally, flour can be fortified with vitamins and trace minerals. The amount of improvers and premixes produced has significantly grown [4].

High-quality raw ingredients and technically sound processing are just two of the numerous variables that affect the food's ultimate quality (consumer packaging, transportation, and incorrect handling at the shop). Additionally, consumers' careless or uneducated handling may have an impact on final quality. Thus, from the processing of raw materials into finished goods to consumption, quality control is crucial along the whole food chain [4].

Chapter 01

CEREAL GRAINS

The primary nutritional source of plant proteins, carbs, and energy worldwide is cereal grains [1]. Up to 35% of grains are being used for animal feed, whereas just 41% are used for human consumption. As a source of plant proteins that are both healthful and environmentally friendly, cereals have been underappreciated, but they have the potential to be a significant contributor to the shift to a more sustainable food system for a healthier diet [1]. Though lysine is frequently the limiting amino acid, cereal plant proteins are of high nutritional quality. Cereals, when eaten as whole grains, contain phytochemicals and dietary fiber, which are components that are beneficial to health. Using grains for traditional foods and, theoretically, new foods and ingredients instead of feed could reduce climate change and increase protein security [5].

1. Cereal grain definition

Cereals are the most essential staple meal for people all over the world and are the primary ingredient in animal feed. Cereals are also being used to produce energy more recently, for instance, by fermentation that produces biogas or bioethanol. The main cereals include barley, sorghum, millet, oats, rye, corn, wheat, and rice. On around 60% of the world's arable land, they are grown. The largest percentage of area used for cereal cultivation is devoted to wheat, corn, and rice, which also yield the most cereal grains [6].

One of the main components of the human diet, cereals have a big impact on health. They therefore play a significant role in the food business. A thorough summary of all the significant cereal and pseudo-cereal species, from their composition to their application in food items, is given by cereal grains for the food and beverage sectors [6].

Cereal Grain Science examines the properties, structure, and composition of cereals as well as the changes or reactions they go through. The grains that form the foundation of the global food supply are produced by cereals, which include plants like wheat, rice, corn, barley, rye, oats, and millet. Cereal chemistry is a growing scientific field because of the significance of cereals as sustenance for both humans and animals [6].

Despite the fact that the field is very specialized, it is actually very diverse. This diversity is demonstrated by looking at the wide range of fields that use cereal chemists' expertise. In basic research, the cereal chemist may study the biochemical elements of cereals, such as their proteins, lipids, carbohydrates, and enzymes. Several of this research [7] are highly technical and use advanced analytical tools and methods. Cereal chemists, on the other hand, might work for a food company that produces food in practical ways, including milling flour, baking, malting, brewing, or making pasta.

Cereal chemists or technologists may work in food companies as product developers or quality control personnel, using their knowledge of food manufacturing to evaluate items for consistently high quality [7].

All cereals are grown in essentially the same way. Since they are annual plants, a single planting results in a single crop. But the pressures on climate are different. "Warm-season" cereals (corn, rice, sorghum, and millet) are cultivated all year round in tropical lowlands and during the frost-free season in temperate areas.

Sorghum and millet are suited to dry climates, while rice is primarily grown in flooded fields. Moderate climates are ideal for the growth of "cool-season" cereals, such as wheat, rye, barley, and oats.

There are two types of wheat, rye, and barley: winter and spring. The winter variety is sown in the fall and reaches maturity in the early summer; it needs low temperatures to vernalize. Spring cereals, which are sown in the spring and mature in the middle of summer, are more susceptible to freezing temperatures, require more watering, and provide lower yields than winter cereals.

In the form of a caryopsis, cereals yield dry, single-seeded fruits known as "kernel" or "grain," in which the pericarp (fruit coat) is firmly attached to the testa (seed coat). Grain weight and size vary greatly, ranging from small millet grains (9 mg) to quite large corn grains (350 mg). Cereal grains have a very consistent anatomy: the germ and endosperm are enclosed by fruit and seed coats (bran), which are made up of the aleurone layer and the starchy endosperm.

The husk of rice, barley, and oats is fused with the fruit coat and cannot be easily removed by threshing, unlike common wheat and rye (bare cereals).

1.1. Classification of cereal grains

In botany, cereals are classified as grasses and are members of the Poaceae monocot family (Figure 1). Being members of the *Tribus Triticeae* and the subfamily Pooideae, wheat, rye, and barley are closely related. Rice, corn, sorghum, and millet have distinct evolutionary lines, while oats are a distant relative of the Triticeae within the Pooideae subfamily. The five kinds of wheat that are cultivated are the diploid einkorn (AA), the tetraploid durum and emmer (AABB), and the hexaploid common (bread) and spelt wheat (genome AABBDD).

An artificial hybrid of rye and durum wheat is called triticale (AABBRR). There are several varieties of each cereal species that have been created through breeding to maximize their agronomic, technical, and nutritional qualities [7]. Cereals are arranged botanically in Figure 1. All grains are members of the Poaceae family. The primary harmful cereals, such as wheat, rye, and barley, are members of the Pooideae subfamily and have CD-eliciting epitopes. However, those with celiac disease (CD) can safely consume rice, millet, and corn.

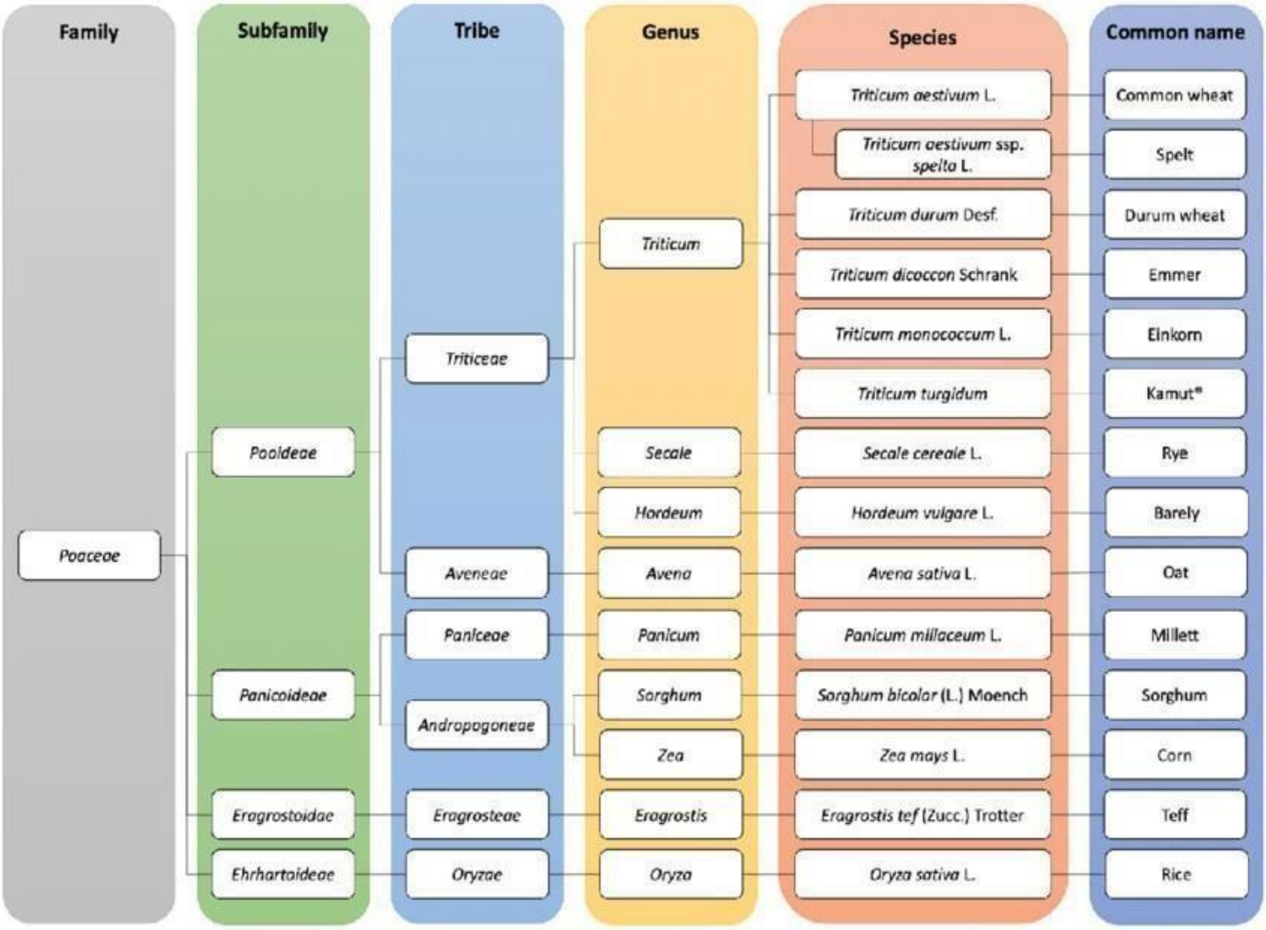


Figure 1. Botanical classification of cereals [7].

One promising technology for quick identification and grain handling automation is machine vision. Recent developments in personal computer memory and processing capacity have made it possible to use machine vision systems for online agricultural product inspection. Numerous academics have used pattern recognition and digital image analysis to objectively identify wheat grains [8].

Models that combine morphological, color, and textural data outperform models that rely solely on one feature set, according to research findings [8]. In order to increase the classification accuracy of cereal grains, it was hypothesized in this study that a new feature vector (wavelet) may be added and combined.

A common method for describing and categorizing the texture of images is wavelet analysis [9]. Wavelet textural characteristics have recently been applied to the classification of food and agricultural products. One signal processing method for analyzing the texture of multi-resolution images is wavelet analysis. As proposed by Choudhary et al., [9] it is carried out by breaking down the images into many wavelet components using a filter bank. Discrete wavelet transforms can be used to analyze image textures at various resolutions.

Table 1 summarizes the main cereals and pseudocereals currently allowed or not in the gluten free diet (GFD) [9]

Table 1. Cereals and pseudocereals and their inclusion in the gluten free diet (GFD) [9].

Allowed	**Not Allowed**	
	Cereals	
Corn	Wheat (Spelt, semolina, durum)	
Rice	Rye	
Sorghum	Barley	
Oat *	Kamut	
	Pseudocereals	
Buckwheat	Quinoa	Amaranth

*Still a matter of debate.

1.2. Cereal sectors

Agriculture and food systems are essential to human welfare. When it comes to food security, these systems are essential for many farmers' livelihoods and earnings in addition to providing safe, wholesome food. These same processes are essential to economic and rural development. In order to meet the growing demands for food, animal feed, and biofuels, cereal output worldwide is essential to the food security goal. After the vegetable/horticultural and dairy industries, the cereals industry in the EU contributed about 272.6 million tons of the overall agricultural production value in 2022, ranking third. For several member states, especially those in the north where it is strongly established, it is a significant industry. A variety of cereal crops are produced in each of the member states [10].

In addition to structural issues, the EU cereal industry is also dealing with financial and climatic difficulties. A more efficient industry is indicated by advancements in the scientific and technological domains, such as plant breeding and digitization, as well as changes in the policy framework, as demonstrated by the new common agricultural policy (CAP) recommendations. Nonetheless, there are numerous sectoral difficulties. The CAP reform process for the post-2020 era, which promises a new delivery model and strategic plans, is a change from the status quo. On the supply side, new risks in global agricultural markets include regulatory reactions to novel plant breeding methods and the growing probability of extreme weather occurrences [9]. The cereal industry operates in an agricultural environment that is attempting to counteract the loss of plant protection goods that were previously relied upon, as well as a globe that is grappling with how to implement the Paris Agreement. The profitability and sustainability of the industry will be impacted by each of these issues. In terms of output value, the EU's cereals industry ranks first, behind the dairy and vegetable/horticultural plant industries (Figure 2).

In 2018, 80 million hectares, or 45%, of the total usable agricultural area (UAA) was made up of arable crops. A third of the UAA is made up of permanent grassland (almost 60 million hectares), while cereals make up 31%. Fodder area (21 million hectares) and permanent crops (11.5 million hectares) share 12% and 6% of the total UAA, respectively. 4% is made up of fallow land. [9].

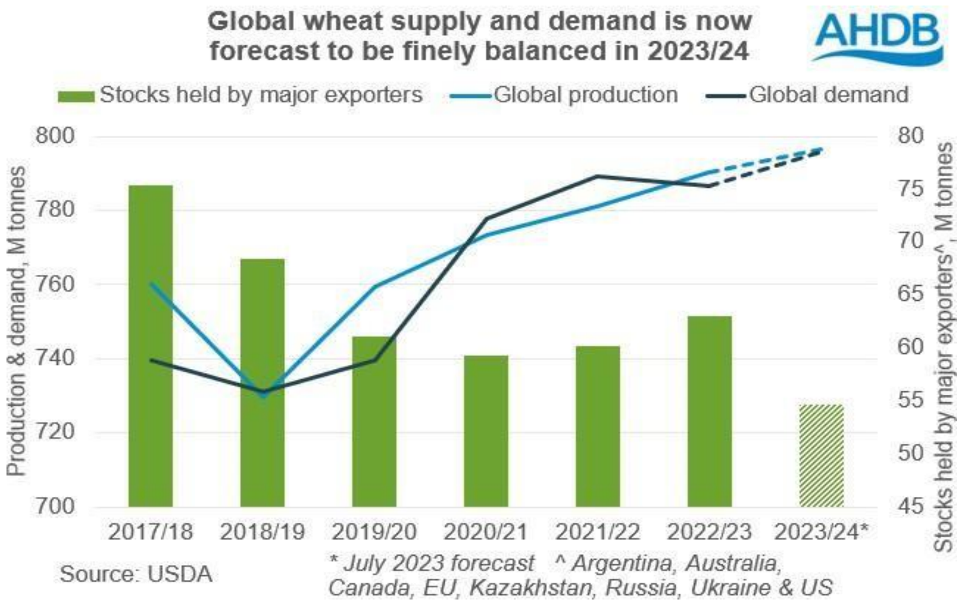


Figure 2. Bakery and Cereals Market Growth

1.3. Composition of Cereal Grains

Cereals consist of 50–80% carbs and a smaller but still significant amount of lipids (1–10%) and proteins (5–6%) (Table 2). Phosphorus, calcium, magnesium, potassium, iron, zinc, and copper are among the mineral salts (1.5–2.5%) and vitamins (thiamine, riboflavin, niacin, pyridoxine, biotin, folic acid, vitamin E, and vitamin A) that are abundant in whole grains [11]

Table 2. Nutrients of cereals [11].

Cereal	**Proteins**	**Lipids**	**Fiber**	**Ash**	**Carbohydrates**
Wheat	14.3	2.3	2.8	2.2	78.4
Rye	13.4	1.8	2.6	2.1	80.1
Barley	10.8	1.9	4.4	2.2	80.7
Millet	14.5	5.1	8.5	2	71.6
Oat	11.6	5.2	10.4	2.9	69.8
Amaranth	16.6	7.2	4.1	3.3	59.2
Buckweat	12.3	2.3	10.1	2.3	66
Quinoa	16.5	6.3	3.8	3.8	69

Cereal grains consist of four distinct components: the bran, endosperm, germ, and aleurone layer. The bran, the aleurone layer, and the germ contain more proteins with essential amino acids, vitamins, minerals, fibers, lipids (which are more prevalent in the germ), and bioactive substances (phenolic acids, flavonoids, alkylresorcinols, avenantramides, tannins, carotenoids, lignans, and phytosterols) than the endosperm, which is rich in starch and reserve proteins (prolamins and glutelin) [12] (Figure 3).

The fourth-biggest cereal crop worldwide is barley. It is mostly utilized for food production, beer manufacture, and feeding. Due to its unique chemical makeup and health advantages, barley is gaining more attention from food and agricultural professionals. Compared to other cereal crops like wheat, rice, and maize, barley grains are higher in dietary fiber (such β-glucan), both of which are good for human health. Diets high in certain compounds have been shown to protect against diabetes, heart disease, and high blood pressure. It is often known that barley has a lot of potential as a functional or healthful food [11].

The final purpose of barley grains is directly correlated with their chemical makeup. High-protein barley is suitable for use in animal feed and human consumption, whereas low-protein barley is typically used for brewing or malting. Generally speaking, barley grains are mostly composed of minerals, proteins, lipids, and carbohydrates, along with a number of secondary metabolites such vitamins and phenolic compounds [11].

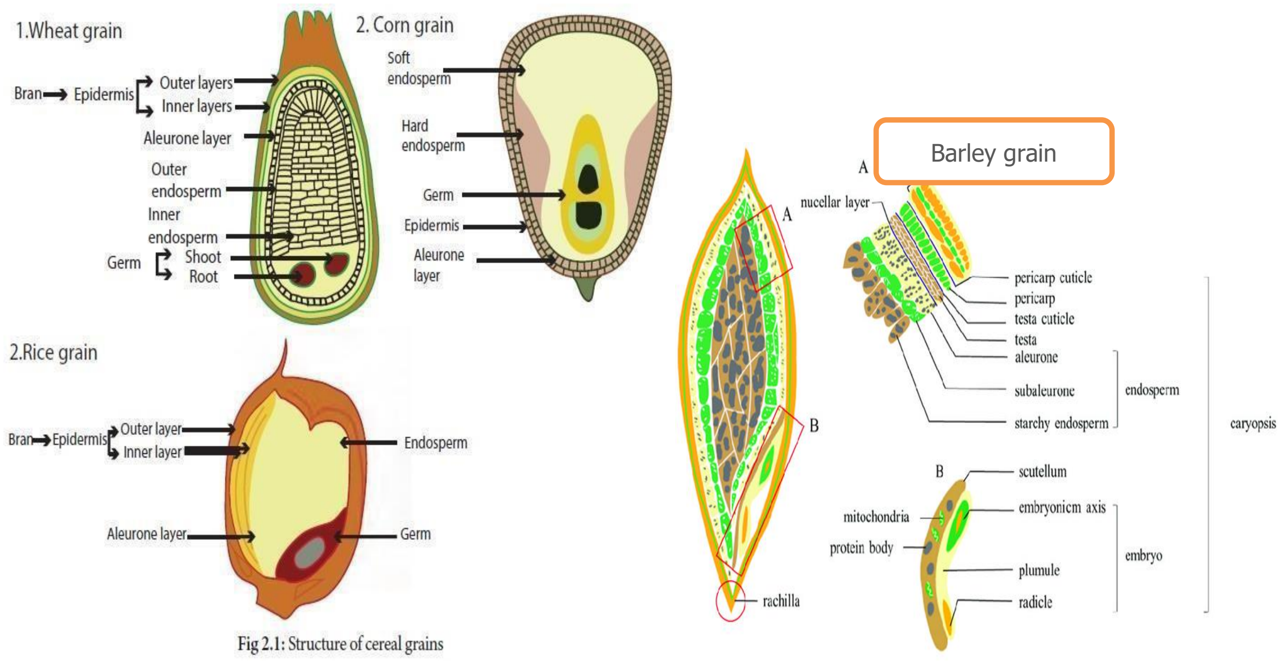


Figure 3. Structure of cereal grains [12].

A common component of many diets, whole grains have been associated with positive health outcomes. These positive effects appear to be caused, at least in part, by the presence of dietary fibers, however the types and total amounts of these fibers vary throughout cereals. Both soluble and insoluble fiber can be found in whole grains and pseudo-cereals; the most prevalent types are cellulose, fructan, xyloglucan, and arabinoxylan-glucan [13].

Vitamins A, E, and K, thiamine, riboflavin, niacin, pyridoxine, biotin, folic acid, and pantothenic acid are among the several vitamins found in cereals [14]. A considerable amount can be eliminated during the refinement process since they are particularly dispersed throughout the germ and integument [14].

Furthermore, the degree of refinement, soil composition, and cultivar all influence the absolute richness of vitamins and minerals [11, 13].

In cereals, compounds with antinutrient activities include α-amylase inhibitors, trypsin inhibitors, and protease inhibitors [13]. The inhibition of α-amylase function increases time of carbohydrate absorption [14], while in human diets trypsin inhibitors reduce protein digestion and consequent amino acids availability, leading to decreased growth rate and pancreatic hyperplasia [11], like protease inhibitors [13].

Nevertheless, several studies demonstrated that enzyme inhibitors, including alpha-amylase, alpha-glucosidase, and lipase inhibitors, might prevent type 2 diabetes and obesity [14].

Tannins are high molecular weight polyphenol compounds which link with carbohydrates and proteins with intra- and inter-molecular hydrogen bonds, acting as antioxidant, anticarcinogenic, immunomodulatory, and cardioprotective agents [14]. Antioxidants have a beneficial effect, but tannins may hinder the absorption of some minerals from food, including iron, copper, and zinc [14]. Cereal grains, seeds, legumes, fruits, juices, cocoa beans, tea, wines, and nuts all contain them. They are among the most abundant secondary plant metabolites [14].

1.3.1. Carbohydrates [15]

Carbohydrates are the most prevalent category of elements in cereal grains, accounting for 78.4% of their content (Table 2). The primary carbohydrate is starch (55–70%), which is followed by smaller components such sugars (3%), cellulose (2.5%), arabinoxylans (1.5–8%), β-glucans (0.5–7%), and glucose fructans (1%).

1.3.1.1. Starch

An essential component of our diet, starch is the main storage carbohydrate found in cereals. The textural qualities of many foods, especially bread and other baked items, depend on starch because of its special qualities. The generation of bioethanol and biogas also uses starch as a feedstock these days [15].

a. Amylose and Amylopectin

Granular forms of starch are found only in the endosperm. The two water-insoluble homoglucans, amylose and amylopectin, make up this substance. 75–75% amylopectin and 25–28% amylose make up cereal starches on average [16]. Some mutant genotypes may have a different ratio of amylose to amylopectin. The amylopectin content of "waxy" cultivars can reach 100%, whereas "high amylose" or "amylostarch" cultivars can have up to 70% amylose. This changed amylose/amylopectin ratio has an impact on these cultivars' technical characteristics [16]. One potential source material for the synthesis of enzyme-resistant starch is high-amylose wheat.

A -(1,4)-linked d-glucopyranosyl units make up amylose, which is nearly linear. Certain compounds also have -(1,6)-links that give them slightly branching architectures [16]. They have a molecular weight (MW) of 8×10^4 to 10^6 and a degree of polymerization ranging from 500 to 6.000 glucose units. It is amylopectin that gives starch its granular consistency. Because it contains between 30.000 and 3.000.000 glucose units, its MW (10^7 - 10^9) is significantly higher than amylose's. High levels of branching are found in amylopectin, a polymer composed of d-glucopyranosyl chains joined by -(1,4)-linked glycosidic connections, commonly known as branchpoints [16].

Depending on the molecular location, the length of the α-(1,4)-linked chains varies from 6 to over 100 glucose units. One can differentiate the branching β- or inner chains, which are further classified into β_1, β_2, β_3, and β_4 chains, from the unbranched α or outer chains [17]. There is only one C chain that contains the reducing glucose residue, which e "terminates" the molecules.

The structure of amylopectin resembles a tree, with chains arranged in clusters along the molecule's axis. [17]. Short A- and B_1 chains of 12–15 glucose residues form the clusters which have double-helical structures. The longer, less abundant B_2, B_3, and B_4 chains interconnect 2, 3 or 4 clusters, respectively. B_2 chains contain approximately 35-40, B_3 chains 70-80, and B_4 chains up to more than 100 glucose residues [18].

b. Starch Granules

Starch is found in the endosperm as intracellular granules that vary in size and form according on the kind of cereal. Unlike the majority of plant starches, the starches found in wheat, rye, and barley typically have two granule populations that vary in size.

It is possible to differentiate between huge ellipsoid granules with mean diameters of about 20 mm and small spherical B-granules with an average size of 5 mm [18]. Native starch granules are birefringent under a polarization microscope, which suggests that they contain organized, partially crystalline structures. The main source of the 20-40% degree of crystallinity is amylopectin's structural characteristics [18].

The macromolecules are believed to be positioned perpendicular to the granule surface [18], with the molecules' nonreducing ends pointing in that direction.

A model of the microscopic to nanoscopic arrangement of starch granules has been proposed [18]. Several hundred nanometers in periodicity, alternating concentric growth rings can be seen at the tiny level.

They have alternating amorphous and semicrystalline shells. Noncrystalline amylopectin is present in the latter, which are less dense and abundant in amylose. They also have crystalline and amorphous lamellae that alternate, each measuring roughly 9–10 nm [17].

In crystalline regions, amylopectin double helices of A and B1 chains are arranged in parallel, and left-handed superhelices that may be 18 nm broad are created from double helices. The branching sites of amylopectin are represented by amorphous areas, which may also contain a small number of amylose molecules. Over time, the lamellae are arranged into bigger spherical blocklets that range in diameter from 20 to 500 nm [19]. Several crystal forms may contain the amylopectin double helices. Retrograded starch, high amylose cereal starches, and certain tuber starches include the more hydrated tube-like B-type, but the majority of cereal starches contain the extremely tightly packed A type [19]." Mixtures of categories A and B are referred to as C-type.

c. Interaction with Lipids

In particular, amylose can form helical inclusion complexes with polar lipids; this can happen with both native (starch lipids; see below) and gelatinized starch [20]. A left-handed single helix is formed by amylose during the gelatinization process, and the middle cavity contains the polar lipid's nonpolar moiety [16]. There is a V-type X-ray diffraction pattern that results from the inclusion complexes. The retrogradation properties of the starch are significantly impacted by the presence of polar lipids because amylose-lipid complexes are not involved in the recrystallization process [15]. Complex formation is however, strongly affected by the structure of the polar lipid [21]. Monoglycerides are more active than diglycerides, and saturated fatty acids are more active than unsaturated ones, for instance, because inclusion complexes preferentially form with linear hydrocarbon chains and molecules that include a single fatty acid residue. Lipids, namely lysophospholipids (lysolecithin), are also trace levels of grain starches (0.8–1.2%). [16]. They are linked to amylose and the outer branches of amylopectin as so-called starch lipids [20]. These lipid compounds delay the onset of gelatinization and alter the starch's characteristics, particularly while baking.

1.3.2. Nonstarch Polysaccharides (NSP)

Cell walls are the primary source of polysaccharides other than starch, which are significantly more prevalent in the outer layers of grains than in the interior ones.

Accordingly, a higher extraction rate corresponds to a higher content of NSP. From a nutritional perspective, NSP is dietary fiber, which has been linked to favorable health outcomes; for instance, cereal dietary fiber has been linked to a lower risk of chronic lifestyle diseases like gastrointestinal cancer, cardiovascular disease, and type II diabetes [21]. Furthermore, technological features for wheat and rye's arabinoxylans (AX) have been described [21].

1.3.2.1. Arabinoxylans (AX)

The majority (85–90%) of the so-called pentosans are AX. The amount of AX in various grain species varies. In contrast to wheat, which has only 1.5–2% AX, rye has the highest levels (6–8%). AX can be separated into two fractions based on its solubility: water-extractable (WEAX) and water-unextractable (WUAX). The former accounts for 15–25% of total AX in rye and 25–30% in wheat [21]. Specifically, WEAX is quite useful for baking bread.

AX is composed of linear b (1,4)-d xylopyranosyl-chains that can be replaced with α-l-arbinofuranose at the O_2 and/or O_3 locations [22]. Ferulic acid is one of AX's specific minor constituents; it is an ester linked to arabinose at the O_5 position [22].

AX of different cereals may vary substantially in content, substitutional pattern and molecular weight [22]. WEAX mainly consist of two populations of alternating open and highly branched regions, which can be distinguished by their characteristic arabinose/xylose ratios, ranging between 0.3 and 1.1 depending on the specific structural region [18]. WUAX can be solubilized by mild alkaline treatment yielding structures that are comparable to those of WEAX [23] .

1.3.2.2. β –Glucans

Although β-glucans, also known as lichenins, are found in less than 2% of other cereals, they are mostly found in barley (3–7%) and oats (3.5–5%).

They are composed of linear D-glucose chains connected by mixed β-(1,3)- and β-(1,4)-glycosidic bonds, which make up their chemical structure. AX is less water soluble than β-glucans (38–69% in barley, 65–90% in oats), and they produce viscous solutions that can obstruct wort filtration in the beer-making process in barley [24].

1.3.3. Proteins

Variations are obvious, but the average protein content of cereal grains falls within a very small range (8–11%) (Table 2). The percentage of wheat grains, for example, might range from less than 6% to over 20%. The amount and timing of nitrogen fertilization are particularly significant, and the genotype (cereal, species, variety) and growth conditions (soil, climate, fertilization) influence the content. Despite being dispersed throughout the grain, the concentration of proteins varies significantly within each compartment. For example, the starchy endosperm of wheat grains contains 13% of proteins, the bran 7%, and the germ and aleurone layer over 30% [25].

The majority of the proteins in grains are found in the starchy endosperm, which is where white flours made by milling and sifting grains come from, despite the varying ratios of these compartments. Grain products of the most importance are white flours. White flour proteins are hence the subject of the majority of the literature on cereal proteins. Table 2 lists the different cereals' flour proteins' amino acid compositions.

The fact that glutamic acid is nearly exclusively found in its amidated state as glutamine is characteristic of all flours. [27]. This amino acid typically makes up 15–31% of the total, with proline coming in second (12–14%) for wheat, rye, and barley. Additional important amino acids include alanine (4–11%) and leucine (7–14%). There is only very little of the biologically necessary amino acids histidine (1.8–2.2%), lysine (1.4–3.3%), methionine (1.3–2.9%), and tryptophan (0.2–1.0%). In an effort to increase the amount of necessary amino acids, breeding and genetic engineering are being used. These strategies have worked well for high-lysine corn and barley [28].

1.4. Impact of farming methods on grains constituents

Numerous investigations have confirmed that storage protein structures and amounts are subject to constant alteration from the plant's growth phase to the final product's processing. Due to wheat's significance as a special "bread cereal," the majority of research has concentrated on gluten proteins. However, in theory, the impact of outside factors is comparable for all cereal proteins [29].

1.4.1. Fertilization

For the best possible plant development, a mineral supply is necessary while the plant is growing. Common wheat benefits greatly from nitrogen (N) fertilization since a high N supply increases the flour's protein content and, consequently, the bread's volume. Different N amounts during fertilization showed that while the amounts of gluten proteins rise with increased N supply, the amounts of albumins and globulins are hardly affected [30]. An higher gliadin/glutenin ratio is the outcome of more noticeable effects on gliadins than on glutenins. Specifically, a high supply of N boosts the proportions of w type gliadins.

Sulfur (S)-containing fertilizers were not commonly utilized for cereal crops in the past because the soil already had adequate amounts of S due to air pollution from industry and transportation. S availability in soils has drastically decreased due to the substantial decline in S input from atmospheric deposition over the past few decades. This has resulted in a severe S shortage in cereals, which has a significant impact on protein composition and technical qualities. S shortage in wheat causes a sharp rise in S-free w-type gliadins and a fall in S-rich g-gliadins and LMW-GS. [31]. Moreover, S deficiency has been reported to impair dough and bread properties.

1.4.2. Infections

Fusarium strains that infect cereal plants cause individual spikelets to prematurely fade, followed by the fading of the entire ear. The trichothecene deoxinivalenol, for instance, can contaminate cereals and flours with mycotoxin during an outbreak of this sickness. Research conducted on wheat revealed that Fusarium infection resulted in a noticeable decrease in the amount of total glutenins and HMW-GS, as well as decreased dough and bread quality [32]. Common wheat glutenins have been found to be more severely impacted than emmer and bare barley storage proteins [30, 31].

1.4.3. Germination

In dry grains, proteins and other components remain stable. However, a water supply causes grains to germinate and activates enzymes, including peptidases and amylases. During germination, the latter have been demonstrated to rapidly degrade the prolamins of wheat, rye, barley, and oats [32]. Research on the Osborne fractions of wheat showed that whereas albumins and globulins were hardly impacted, monomeric gliadins and polymeric glutenins were both severely broken down over 168 hours of germination at 15–30 °C [29]. The degradation of gluten proteins has a drastic negative effect on the bread-making quality of wheat.

1.4.4. Oxidation

Glutathione and other LMW thiols, which are found in significant amounts in grains, are known to influence the structures and functional characteristics of polymeric storage proteins through thiol/disulfide interchange processes that occur during dough manufacture [27]. Week-long air storage of flour (direct oxidation of LMW thiols) and L-ascorbic acid treatment (indirect oxidation mediated by glutathione dehydrogenase) are advised to prevent this detrimental effect on the quality of wheat used to make bread.

1.4.5. Enzymes

The improved sensory and nutritional quality, longer shelf life, and delayed staling of breads made from rye and wheat sourdoughs have increased customer interest in these products. However, there is significant degradation of wheat storage proteins, which give dough its viscoelastic and gas-holding qualities as well as the texture of the bread crumb [33]. The main cause of protein degradation during fermentation is the presence of acidic peptidases in flour, which are triggered by the decreased pH brought on by Lactobacillus strains. Total glutenins and the glutenin macropolymer showed the most declines. In comparison to the α/β and ω types, the g-type showed a more marked and less significant reduction in monomeric gliadins.

1.4.6. Heat

When bread is baked, the proteins undergo a harsh heat treatment, with the crust (the outer layer) reaching temperatures of over 200 °C and the crumb (the inside layer) reaching temperatures of around 100 °C. Both glutenins and gliadins have significant structural degradation, according to HPLC examination of the crust proteins from wheat bread [34]. Total gliadins with 60% ethanol had much lower extractability in crumb than those from flours. The single gliadin types are affected differently; α/β and ω types are affected substantially more than ω type gliadins. The majority of gliadins may be recovered in the glutenin fraction following the elimination of disulfide bonds, indicating that disulfide linkages are the primary heat-induced crosslinks that bind gliadins to glutenins.

1.4.7. High Pressure

Heat and hydrostatic pressure have comparable effects. When gluten is treated with pressure between 300 and 600 MPa for 10 minutes at 60°C, the extractability of gliadin is significantly reduced. Within the gliadin types, the α/β and ω type gliadins that include cysteine are sensitive to pressure and are transported to the ethanol-insoluble glutenin fraction, while the ω type gliadins do not. Pressure-induced aggregation has been attributed to the cleavage and reorganization of disulfide bonds [33].

1.5. Major Cereal Grains production and use around the world

For thousands of years, cereal grains have formed the mainstay of the human diet and have greatly influenced the development of human civilization. The everyday life of billions of people worldwide depends on staple foods like rice, wheat, and maize, and to a lesser extent, sorghum and millets [34]. Cereal grain consumption accounts for over half of the daily caloric intake in the world. In order to satisfy consumer sensory expectations, the majority of grain used for human consumption is ground to remove the bran (pericarp) and germ [35, 36].

Dietary fiber, phenolics, vitamins, and minerals are among the vital components that are removed from grains during the milling process. Therefore, despite the wealth of research supporting the health benefits of eating whole grains, there are still obstacles in creating food products that satisfy consumer demands while including sizable amounts of whole grain components [37].

Grain production worldwide is influenced by a number of factors, chief among them being economic, cultural, and environmental. The two most important environmental elements that affect the crops grown in a particular area are most likely temperature and water availability. The predominant crops in areas with non-limiting water availability are rice and, to a lesser degree, maize. Since rice is frequently grown in flood-prone environments, it is likely the cereal crop that uses the least amount of water and is hence most vulnerable to water shortages. The majority of rice-producing locations require either abundant rainfall or big bodies of readily accessible fresh water. This describes the parts of Asia that generate the majority of the world's rice [36].

Similar to rice, maize is also somewhat vulnerable to drought, albeit not as much. Since neither rice nor maize can tolerate frost, they need to be grown in warm climates. Consequently, these crops are cultivated in the spring and harvested in the summer in temperate locations. Conversely, a greater variety of conditions, from very low water availability to high water availability, are used to grow wheat [34].

Furthermore, wheat is grown extensively in temperate locations throughout the winter and spring due to its ability to tolerate a wide range of temperatures. Though greater temperatures during flowering and grain filling can severely reduce wheat output, wheat is also frequently produced in warmer climates. Sorghum and millet are two crops that are generally grown in areas where drought stress is a significant problem, such as semi-arid regions in Africa and India. Because it can withstand colder temperatures, barley, the other main grain produced, is primarily grown in northern Europe, the northern United States, and Canada.

Table 3. Major cereal grain world production statistics (2010) [38]

Commodity	Production area (Million ha)	Production (MMT)	International trade (MMT)
Maize	160	825	94
Wheat	226	650	122
Rice	162	680	30
Barley	54	150	17.3
Sorghum	40	60	6.3

MMT – Million metric tons paddy rice (values in parentheses represent polished rice).

Rice, wheat, and maize (corn) are the three most significant food crops in the world. More over half of the calories that humans consume come directly from the three cereal grains. Furthermore, in some parts of the world, especially semi-arid regions of Africa and India, other minor grains like sorghum and millet contribute significantly to total caloric intake. In Burkina Faso and Niger, for instance, sorghum and millet account for up to 85% of daily calorie consumption [38]. A significant portion of the production of cereal grains, especially corn, barley, sorghum, and oats, is also used to make animal feed, which indirectly aids in human nutrition. The following sections provide a summary of the major cereal grains' overall significance to the global food basket.

1.5.1. Rice

The most significant calorie source for humans is rice. Of all the cereals, rice is primarily farmed for human consumption; very little is used for other purposes. About 21% of the world's per capita caloric intake and 27% of the calories consumed per capita in developing nations come from rice. Up to 80% of calories in the nations with the greatest consumption rates—Vietnam, Cambodia, and Myanmar come from rice. Of the 440 million metric tons (MMT) of polished rice produced in the world in 2020 (Table 3), 85% went into direct human food supply [39]. In comparison, just 15% of maize production and 70% of wheat production were directly consumed by people. Rice production (and consumption) is quite regional; 92% of the world's rice is produced in Asia [38], with China and India producing 50% of the world's rice in 2020 (Table 3). Rice farming occupies up to 90% of agricultural area in some Asian nations, such as Cambodia.

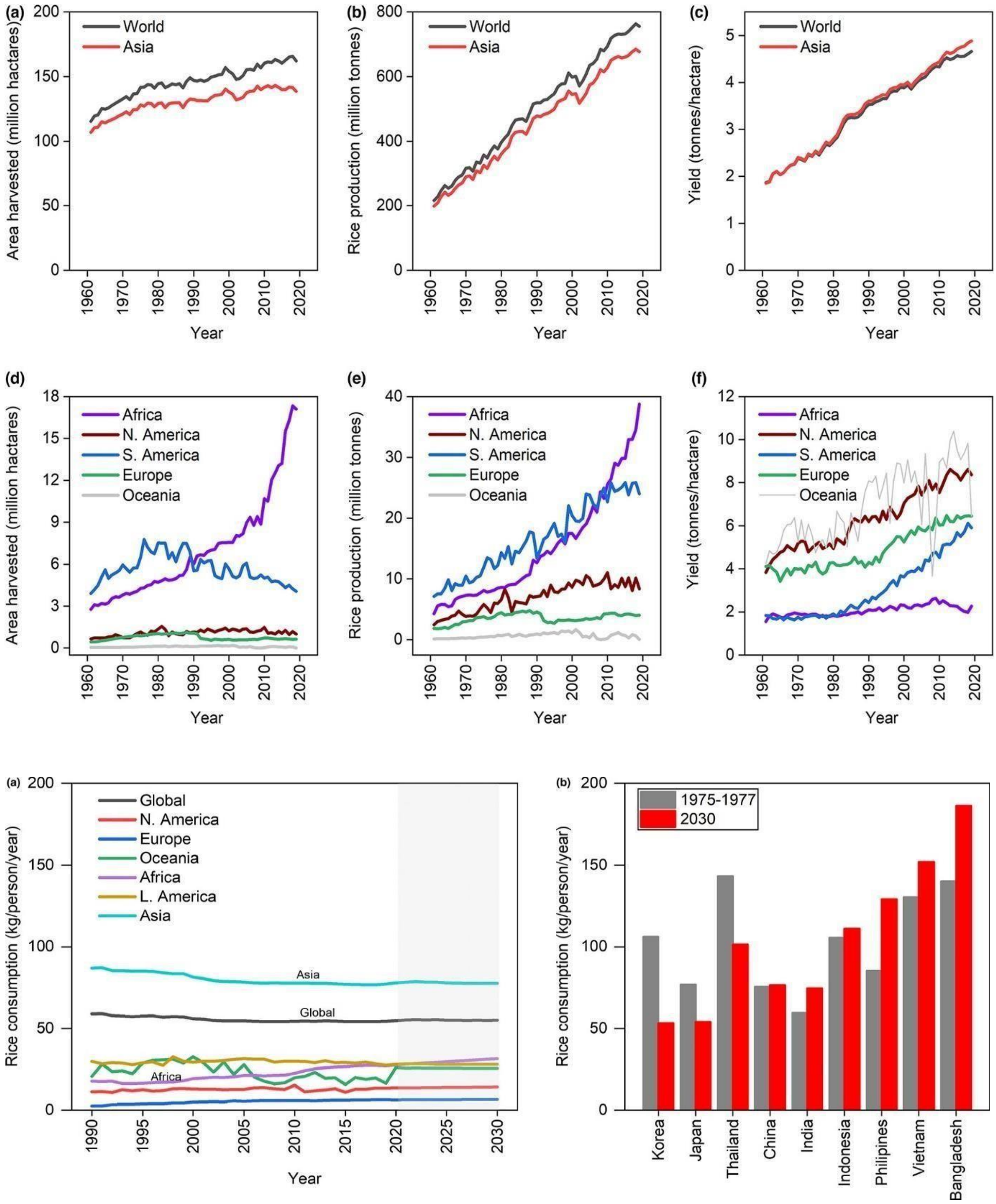


Figure 4. Trends in per capita rice word production and globally consumption [39]

In 2019, the average amount of rice consumed globally per person was 63 kg (milled), with Asian nations accounting for 90% of global rice output. Regional variations in rice consumption are significant overall: For instance, the average yearly consumption per person in 2019 was between 150 and 226 kg in high-use nations including Bangladesh, Indonesia, Myanmar, Thailand, and Vietnam. In comparison, the average yearly consumption per capita in low-use nations such as Mexico, Argentina, and most of Europe was between 6 and 8 kg. Due to the fact that the majority of rice output is utilized to satisfy domestic demand, only 6.8% of it is traded internationally (Table 4). This suggests that not all rice-producing nations typically consume large amounts of rice.

Since just a small portion of the world's rice crop is traded internationally, it is anticipated that as Asia's weak economies grow wealthier and start to diversify their diets, demand for rice would decrease. For instance, South Korea's per capita yearly consumption of polished rice has been progressively declining, from a peak of roughly 140 kg in the late 1970s to 75 kg in 2020 (Figure 4) [39]. China's yearly per capita consumption has been declining since 2000; globally, per capita consumption fell from 66 kg to 63 kg during the same time period (Figure 4). It may be difficult to forecast the total amount of rice food consumed globally per capita in the future, though, as several high-use Asian nations, such as the Philippines (Figure 4), and other parts of the world are seeing notable increases in rice consumption. As economies in many Sub-Saharan African nations develop and people look to expand their diets beyond traditional maize and sorghum/millet, the amount of rice consumed per person is rising significantly. For instance, between 2010 and 2020, the amount of rice consumed per person in Ivory Coast rose from 67 kg to 76 kg [39].

Table 4. Major world producers of cereal grains (2019/2020 data) [39]

Country	*Production (MMT)*	*Production as % of world output*	*Average yield (Ton/ha)*
Maize			
U.S.A.	333	40.4	10.3
China	168	20.4	5.4
Brazil	51	6.2	3.7
Mexico	20	2.4	2.1
India	17	2	2.8
Wheat			
China	115	17.7	4.8
India	81	12.5	2.8
Russia	62	9.5	2.3
U.S.A.	60	9.2	3.0
France	38	5.8	7.5

Rice (milled)			
China	137	31.1	6.6
India	89	20.2	3
Indonesia	36	8.2	5
Bangladesh	31	7	3.9
Vietnam	25	5.7	5.2

1.5.2. Wheat

The most significant source of calories for humans is wheat, which comes in second only to rice. The most significant source of protein for human diets is wheat, although, like other cereals, it lacks lysine and other critical amino acids. Wheat is the most frequently grown food plant worldwide, with 226 million hectares grown in 2009/2010, yielding 650 MMT of grain. This is because it can generally adapt to a wider range of growth circumstances than other main cereal crops (Table 4). China is the world's biggest producer; in 2010, around 30% of the world's wheat came from China and India. However, Australia produces the most wheat per person, with 1.2 MMT per person in 2009.

Wheat flour consumption varies greatly by area, much like rice consumption; in Egypt, Algeria, Israel, and many other Middle Eastern and Eastern European nations, per capita consumption is considerable and frequently surpasses 150 kg/year [39]. Averaging 35 kg in Central America and 17 kg in Sub-Saharan Africa, per capita consumption is significantly lower in other nations that depend more on other cereals [39]. Approximately 66 kilograms of wheat per person, or 48 to 50 kg of wheat flour, were consumed worldwide in 2010; this amount is predicted to stay the same over the next ten years. Over 80% of the wheat supply (including imports) is used for food in developing nations, while less than 50% is used in industrialized nations [39].

Over the past 50 years or so, wheat consumption has risen dramatically in developing nations (Figure 4), offsetting the general decline in consumption in the developed world, despite the fact that the amount of wheat used as a food has remained essentially constant globally per capita. For instance, the amount of wheat flour consumed per person has been increasing rapidly in a number of Asian and Sub-Saharan African nations; in 1970, India used roughly 40 kg of wheat annually, and in 2007, that amount had increased to nearly 66 kg. Rice consumption has decreased in several Asian nations as wheat consumption has increased. This is ascribed to dietary variety brought about by expanding economies and heightened international trade. Earlier trends in wheat flour consumption in the United States followed similar patterns commonly seen in growing economies. From the 1890s to the 1960s, there was a continuous fall in wheat flour consumption (Figure 4), as the American economy grew steadily and people began gravitating more and more toward animal-based products.

The trend, however, started to reverse in the 1960s as rising consumption of wheat flour and other plant-based products brought about by health concerns about eating animal products—specifically, the link between heart disease and cholesterol, according to studies at the time—lasted until the late 1990s, when it reversed again. A low-carb diet craze that was made popular by weight-loss programs was significantly to blame for the fall that started around 2000. These diet plans proposed (with considerable debate) that the U.S.A.'s rising obesity rates and related health issues were mostly caused by carbohydrate consumption, and that drastically reducing carbohydrate intake would reverse the trend. The decreased sensory appeal of regularly consuming low-carbohydrate goods was a major factor in the short-lived low-carb diet trend. In fact, the low-carb movement proved that although humans cannot survive on bread alone, they cannot survive without it [39].

The U.S.A. experience with wheat consumption clearly indicates that health concerns are a major driver of consumer behavior in terms of their food choices. It also illustrates that potential health benefits alone are not enough to sustain a trend in the long term. Food must also meet consumer sensory needs and expectations; this has been a major bottleneck in attempts to provide healthier foods to consumers. The current efforts to position whole grain-based products at the forefront of healthy eating are likely to go nowhere if these lessons from the past are not taken to heart [38].

1.5.3. Maize (Corn)

With 825 million metric tons produced in 2010, maize is the world's most productive crop (Table 4). By far the biggest producer of maize, the United States accounted for 40% of global production in 2010, with China coming in second at 20%. However, only 15% of maize is used for human consumption, compared to the other two major cereals. Maize is an important staple in both Africa and Latin America; in Africa, over 90% of the crop is used for food, and each person consumes over 50 kg of grain on average. Most of the world's food maize is consumed in Sub-Saharan Africa, which accounts for around 30% of global consumption [39]. East and Southern Africa use 90 to 180 kg of maize per person per year, which is more than the rest of Africa. Examples of these nations are Malawi, Lesotho, Zambia, and Kenya. Maize is a particularly significant staple in nations like Mexico, accounting for roughly 45% of daily calorie intake (mainly in the form of tortillas), while the combined amount of all other grains is only about 10% [39].

The amount of maize used for human consumption in the United States is rather small; in 2009, it was reported that each person consumed 15 kilogram, or roughly 2.1% of the 700 kg produced per person. This data, however, only shows direct consumption in the form of snacks, breakfast cereal, grits, etc. The per capita statistics does not include the single biggest food use of corn in the United States, which is as a sweetener. In 2000, the amount of corn sweetener used per capita peaked at roughly 37 kg, and in 2009, it was 30 kg dry weight. Thus, maize is a significant food product in the United

States, where its true per capita food use is close to 60 kg. The use of corn as sweetener is generally categorized under ‘industrial’ uses. A dramatic shift in maize utilization with important consequences to world food prices has occurred in the past 10 years or so. The U.S.A., which accounts for about 60% of world maize export, saw a dramatic increase in use of maize for fuel ethanol production. Between 2000 and 2010, use of maize for ethanol production increased 8-fold from 16 MMT to 128 MMT, partly necessitated by the high oil prices during this time, as well as government policy towards energy independence. Fuel ethanol currently represents the largest domestic use of maize in the U.S.A., at about 44%of total domestic use. This has resulted in a rapid increase in maize prices in the U.S.A. and similar upward pressure on other grains like wheat, and overall food commodity prices. Price of one metric ton of maize was about $80 in 2001, and had gone up to about $300 in 2011. Since the United States accounts for a significant portion of the global export market, global maize prices are largely determined by U.S. price trends. There are worries that the impoverished countries that rely on grains for their fundamental survival may experience greater food insecurity as a result of the increased demand for grains for the manufacture of bioethanol. Clearly, to guarantee global food security, more sustainable renewable energy sources will be needed [39].

1.5.4. Sorghum and Millet

Sorghum and millet output worldwide is significantly less than that of the "big three." For instance, in 2010, about 60 MMT of sorghum and roughly 27 MMT of millet were produced. However, because of their resistance to drought and other agronomic characteristics, these grains are particularly significant in terms of nutrition in several regions of Africa and India. Millets can thrive in regions with less than 350 mm of rainfall since they are particularly drought tolerant (maize requires at least 700 mm). Human consumption accounts for about 80% of millet output and 50% of sorghum production.

Similar to rice, sorghum and millet are usually consumed in large quantities in the areas where they are grown. For instance, in the states where sorghum and millet are grown, per capita consumption surpasses 90 kg, despite the fact that the average yearly consumption in India is approximately 8 kg [40]. More than 80 kg of sorghum and millet are consumed per person in Burkina Faso and Sudan, and more than 90 kg are consumed in Niger, where millet makes over 80% of the country's cereal grain intake [40]. Nigeria, the world's largest producer of sorghum (11.5 MMT in 2010), consumes roughly 50 kg of sorghum per person. In contrast, the United States of America is the world's second-largest producer, but very little of the grain is used for human consumption there; instead, it is primarily used for export and animal feed. However, there is now more interest in using sorghum in food due to mounting evidence of its possible health advantages [40].

Sorghum and millet demand for human food use has been on the decline in India and Africa.

The demand for millet and sorghum as human food has been declining throughout Africa and India. This has been an undesirable development, especially in East and Southern Africa, where maize has entirely displaced sorghum fields and is now the main staple crop. In contrast to sorghum and millet, maize needs uniform moisture distribution during the growth season and is not drought-tolerant. This has led to a decrease in food security in these areas since subsistence farmers who depend on rainfall receive almost no maize harvest during dry spells. Other issues, such as aflatoxin, which is more common in hot, high-stress areas where sorghum and millets are usually cultivated, easily affect maize when it is grown in these conditions and has caused a number of fatalities from contaminated maize intake [40].

Around the world, cereal grains are produced for both human consumption and animal feed. According to Figure 5, the two crops that are produced in the greatest quantities each year are wheat (766 and 1148 million metric tons, respectively) and rice (755 million metric tons). Other cereal crops of global importance include barley, sorghum, and oats. Animal feed can account for as much as 40% of the annual production of all cereal grains. Large amounts of side streams are created because refined grains are frequently utilized in culinary products. Assuming a reasonable 10% protein level for bran, the approximately 160 million metric tons of bran generated annually contains protein. These side streams are currently mostly used for animal feed. Nonetheless, it is generally acknowledged that using food-grade raw materials for animal feed presents a sustainability issue and that using fewer feedstuffs that compete with food would be advantageous. Converting the utilization of cereal grains to direct human consumption would be preferable [40].

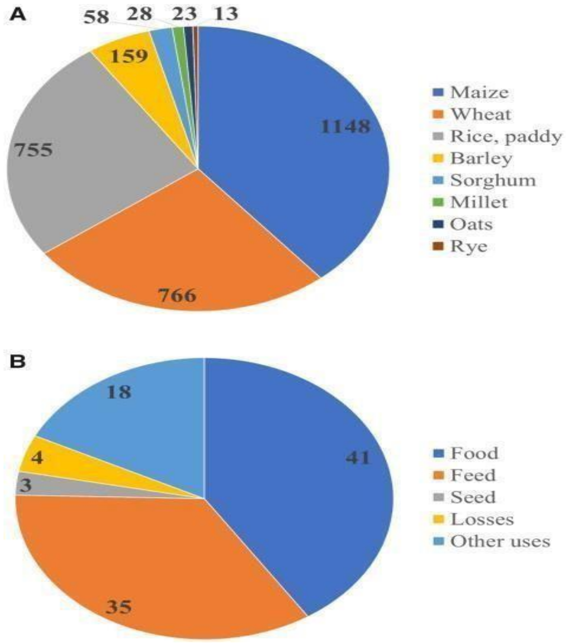
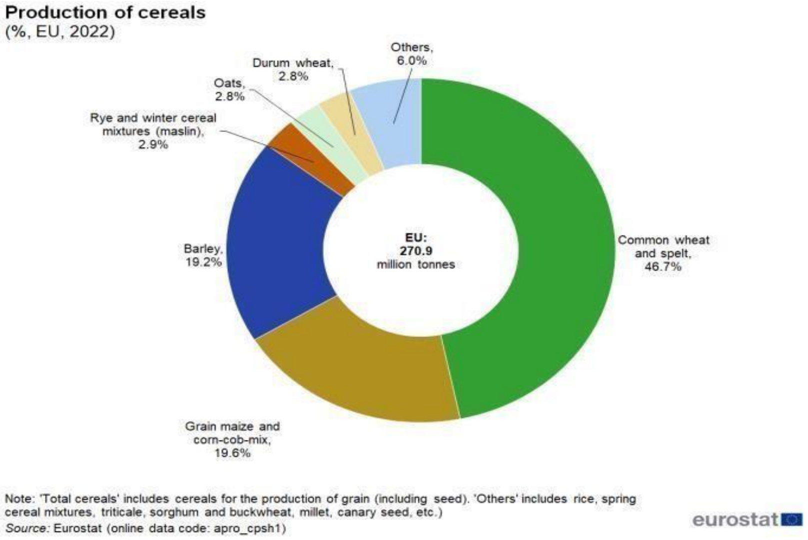


Figure 5. Global production of cereal species (million metric tons/year) (A) and global uses and losses of cereals (%/year) (B) [40]

The main producing country is France, which has the most extensive cereals area, accounting for 17 % of the EU total. It is followed by Poland (14 %), Germany and Spain (both 11 %) **[40]**.

The largest percentage is made up of barley, maize, and common wheat (79%). Just 7% of the entire UAA, or 12 million hectares, is used by the oilseeds complex. Together, France, Germany, and Poland gathered slightly less than half of the EU's total cereal production in 2017, when measured by volume. The share (%) of production for each crop that year is displayed in Figure 6. Since 2015, production levels for barley have remained unchanged, but those for wheat and maize have increased. Soft wheat is the largest crop in the EU, with an average production of 143 million tonnes over the last few years, according to data from the European Commission. It is grown on one-third of the EU's arable land. Wheat accounts for almost half of all cereals farmed in the EU, making it the most widely grown crop in terms of both area and quantity. A fifth more soft wheat has been produced since 2000, primarily as a result of higher yields. Both barley and maize make up one-third of the remaining half of the overall cereal production. Smaller amounts of triticale, rye, oats, and spelt are also farmed as cereals **[40]**.

Maize has become the second most widely grown EU crop, overtaking barley; maize production has increased by 12 % over the past 15 years. By contrast, over the same period barley production has stagnated as a result of a 15 % decline in area, offset by moderate yield growth (Figure 6) **[40]**.



Source: Eurostat, 2022.

Figure 6. Share of main cereals production in the EU, 2022 [40].

Approximately 14% of cereals used domestically in the last five years have been used as seed or for processing in non-food/non-feed businesses, such as bio-energy. Approximately two-thirds of the cereals produced in the EU today are used for animal feed, while about one-third are consumed by humans. Biofuel usage is a mere 3%. Since it is anticipated that the food and feed portion of cereal consumption would only slightly increase, industrial use will become a more significant factor in driving the EU's cereal production growth.

The demand for industrial wheat is expected to expand at the fastest rates (1.9 percent per year between 2016 and 2018 and 2030), followed by barley (0.8 %) and maize (1.6%). Malt processing and brewing accounts for the majority of barley's industrial use and expansion. The Member States' varying local expertise are reflected in the three crops' varying shares utilized in other industries. Even if the overall EU herd is showing diverse tendencies, the demand for animal feed (from pasture, fodder, and arable crops) should increase during the 2018–2030 timeframe. By 2030, total feed usage is expected to reach 275 million tons. The growth patterns of low-protein feed and medium-high-protein diet will differ. The growth will be driven mostly by increased demand for feed made from organic, GM-free, and locally grown crops. The need for fodder, especially silage maize, will also be influenced. [40].

Cereals are used for food and feed, but they also play a part in the production of biofuels, where growth is only predicted to be somewhat higher than it has been in the previous ten years. The demand for cereals, primarily maize, increased by over 120 million tons during the last ten years due to the growth of biofuels, but this growth is anticipated to be almost negative over the projection period. The most recent production, use, and trade prediction from the UN Food and Agriculture Organization (FAO) for 2019 indicated a minor increase in production volumes along with an increase in usage, which led to a decrease in inventories. The production, use, and stock trends during the last ten years are depicted in Figure 7 [40].

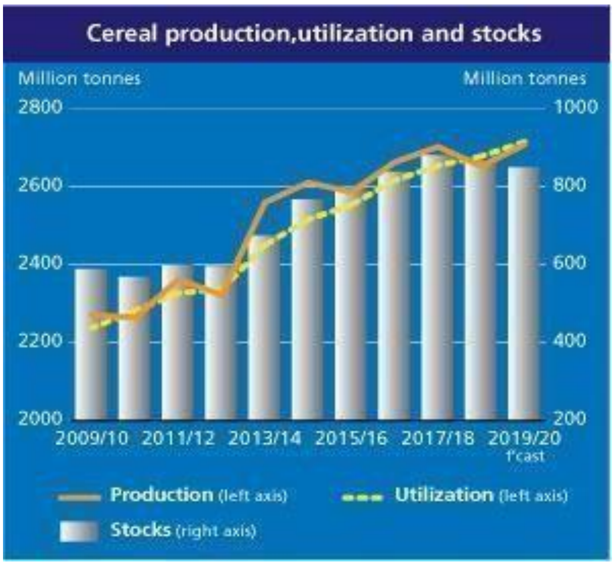


Figure 7. Trends in production, use and stocks from 2009 to 2020. Source: FAO, 2019.

Cereal grains are an important source of dietary proteins, carbohydrates, and energy. A noteworthy 41% of grains are consumed by humans, with up to 35% going toward animal feed. To achieve the goal of substituting animal protein for plant protein, one practical approach is to increase the consumption of plant-based meals [41].

Chapter 02.

Wheat and other

Triticum grains

Whole grain foods are associated with a decreased risk of several diet-related chronic illnesses. Despite being linked to these detrimental effects, wheat, a mainstay of the Western diet, has received less attention for its health benefits than other plant foods like oats or fruit and vegetables. It is time to reconsider wheat as a potential protective food against diet-related diseases because whole grain wheat includes a variety of compounds with recognized health benefits. Research suggests that eating wheat fiber may reduce the incidence of colon cancer, promote laxation, and shorten intestinal transit time.

When indigestible carbohydrates are fermented in the colon, the gut microbiota may change for the better and produce more short-chain fatty acids and other healthy substances. Nevertheless, wheat has many additional substances, including polyphenols, carotenoids, vitamin E, and phytosterols, that may contribute to health and the prevention of disease in addition to the benefits of fiber. The health advantages of eating whole grains may be attributed to these chemicals' cumulative and synergistic actions [41].

2. Algerian wheat varieties

Wheat is one of the oldest food crops. It has been known to exist since 10.000 BC as an agricultural species intentionally cultivated by man [42]. Wheat is a crop that can be grown in a wide variety of soil types and climates, which contributes to its appeal. The primary characteristic that sets wheat apart is its proteins' capacity to unite to form gluten, a protein mass. [42]. Therefore, the only reliable source of flour for making bread worldwide is wheat. The majority of rye bread is formed from a grist of wheat and rye flour, although its near relative, rye, shares part of wheat's capacity to make dough.

Triticum durum

Almost 17 million hectares (ha) are used to grow Triticum durum Desf., one of the most important cereals, with a global yield of 38.1 million tonnes in 2019 [41].

Durum wheat is the first cereal to be grown in Algeria, taking up 1.6 million hectares, or 45% of the total area allotted for cereals [43]. Nonetheless, its output remains negligible, meeting only 20–25% of the demands of a population that is expanding at an accelerating rate, with the remainder being imported [43]. This low output is frequently explained by the fact that most of the land planted to durum wheat is situated on the high plains, where temperatures and rainfall fluctuate greatly both within and between years. Frequent spring frosts and the emergence of sirocco during the grain filling stage also have a significant impact on yields. Durum wheat (*Triticum durum* Desf.) is grown in seven varieties, primarily in northeastern Algeria. These include Waha, Cirta, Wahbi, Bousselem, Semito, GTA dur, and Vitron.

a. Spelt (*Triticum aestivum subsp spelta*)

A primitive wheat is spelt. In southwest Germany and portions of Switzerland and Austria, it was the primary grain used to make bread until the turn of the 20th century. Several central and middle European nations, including Belgium and Germany, currently farm it on 10.000 and 23.000 hectares of land, respectively [41].

According to agronomic research, spelt grows well in less-than-ideal growth conditions and makes greater use of nutrients when cultivated in a low-input system [42], and it shows more resistance to number of pathogens than common wheat.

Due to its reputation as a "healthier, more natural, and less 'over bred' cereal than modern wheat, spelt has garnered renewed and growing interest as a diet for humans over the past few decades. For instance, consumers in Canada have a positive opinion of the wide variety of bread and pastry products made with organic spelt. Compared to wheat, spelt has a greater protein content (18–40%) [42]. But there is less lysine in it. Additionally, spelt has higher levels of zinc, iron, phosphorus, copper, and magnesium, as well as a higher lipid content, particularly in Δ7 avenasterol, than its wheat progenitor [43]. Due to its hexaploid (42 chromosome) nature and similar rheological and technical characteristics to soft wheat, spelt is typically consumed as bread and baked goods.

Baking qualities of spelt cultivars available in the early 1900s were evaluatedby ***Alomari et al.,*** [44] who reported that good loaves of bread could be produced from spelt flours. However, modified baking techniques are needed when creating bread with spelt flour. Though it gets firmer with time, managing spelt flour dough is more challenging since, after kneading, the dough is extremely soft and sticky, making it impossible to follow baking instructions for wheat flour breads directly. This necessitates a lengthy rest period and, in turn, a lengthy fermentation process at a moderate temperature. Last but not least, the loaf capacity is typically smaller than with contemporary wheat cultivars [42].

Nonetheless, spelt appears to have promising technological possibilities for milling and bread-making. In Canada, spring spelt variants have been evaluated for use in bread and pasta products. The findings showed that oxidant-treated spelt flours yielded loaf quantities comparable to those of bread wheats [45].

Spelt can also be successfully used for pasta making. ***Alomari et al.,*** [44] demonstrated that spelt could be effectively used to make alimentary pasta and that the protein level and drying techniques used had a greater influence on the pasta-making potential of spelt than the cultivar.

Additional research on the quality of spelt pasta revealed that spelt flours may be processed to produce pasta with acceptable cooking quality as long as the protein level is greater than 13.5%, which is equivalent to 15% of the protein in grains, and high drying temperatures are applied [44]. Whole-grain and white flours, processed goods, and grains are all made from spelt and sold in organic health food stores. Pre-packaged bread, muffin, and pancake mixes, cold and hot cereals, and various pastas are among the processed goods offered.

Spelt is a hexaploid wheat species (*Triticum spelta*). In addition to minerals and vitamins, it has about 58% carbohydrates, 17% protein, 10% fiber, and 3% fat. Spelt wheat and regular wheat are extremely similar. The grain is protected from weather damage, pollutants, and parasites by a very strong coat, which is the only difference. Spelt wheat is perfect for organic production because it is a very resistant cereal that doesn't require phytochemical treatment [45].

Spelt is offered for sale as a coarse, pale bread that resembles light rye loaves in both color and texture but has a nutty, slightly sweet taste. Although biscuits (cookies) and crackers are also made, you're more likely to find them in a health food store or specialist bakery than in your typical grocery store. Additionally, health food stores and specialty shops carry spelt pasta.

b. *Triticum turgidum*

Triticum turgidum ssp dicoccoides is most likely the wild ancestor of tetraploid wheat that is grown. It can be found in large parts of the Middle East with saline and arid soils [45]. In a study of a wild emmer collection from Israel, 54 genotypes from nine geographical populations were cultivated in supported hydroponics with 100 mm NaCl. The vigor (shoot biomass in nonsaline conditions), salt tolerance (relative dry weight in salt versus nonsaline conditions), and Na+ concentration were measured [45]. Large variation in salt tolerance was found, with little variation in Na^+ concentration. However, genotypes with the highest salt tolerance were generally the least vigorous, and not suitablefor plant breeding [45].

The soil is both saline and wet in numerous areas where land removal or over-irrigation has caused salt to rise to the top. Nine wheat varieties, including two durum wheats, and the waterlogging-tolerant halophyte H. marinum naturally hybridized to produce amphiploids with all of the chromosomes from both the parent wheat and H. marinum [45].Growth responses of one durum and one bread wheat amphiploids indicated that both amphiploids were superior to their respective wheat parents [45]. Disomic chromosome addition lines were successfully developed with Chinese Spring with six of the seven Hordeum chromosomes (apart from chromosome 3).

Waterlogging was not associated with any one chromosome [46], but salt tolerance was associated with the Hordeum chromosome 7 addition line which had lower Na^+ and higher salt tolerance than the other addition lines and was similar to the amphiploid [46]. These addition lines are useful genetic stocks for the identification and introgression of quality genes.

c. Emmer

Triticum turgidum ssp. dicoccum also known as farro (Italian for hulled wheat) has survived in Italy only in a few mountainous marginal areas of central and south Italy where it is cultivated according to organic farming procedures or using very low N fertilisation in competition for yield with other cereals [47]. In addition to being used to make bread, pasta, and biscuits, dehulled farro is typically used in soups. It is used to treat a number of conditions, including colitis, allergies, high blood cholesterol, and even CD; however, because farro includes gluten polypeptides with hazardous epitopes, treating CD is entirely incorrect. Low fat, appropriate protein and vitamin content, high fiber, and minerals are its defining characteristics from a nutritional standpoint, albeit there is a dearth of information on the bioavailability of minerals [47].

d. Triticale (*Triticum secale*)

Triticale is the only plant species created by man who crossed wheat and rye. It was first deliberately produced in 1876 although the first varieties emerged in the 1930s in Russia, but it was until the 1960s when it was commercially planted [47]. Triticale is a hybrid that was created by crossing rye (the father) with wheat (the mother) in order to produce kernels that have the greatest qualities of both cereals, such as improved agronomic performance, gluten functionality, or insect resistance and hardiness. Over the last 20 years, triticale has become more and more popular. About three times as much was produced worldwide in 2013 (14.6 million tons) than in 1993. The majority of triticale that is now farmed, however, does not satisfy gluten requirements and is mostly utilized as feed or fodder. There were over 3.85 million hectares of triticale planted in 2013 [47].

2.1. Histological structure

According to botany, the wheat grain is a single-seeded fruit known as a "caryopsis" or "kernel" that develops inside modified leaves called glumes. Grain dimensions and form can be used as evidence to differentiate between different types [48]. The flour made by milling the wheat grain to make the many wheat-based dishes comes from the inner endosperm of the grain.

A naturally occurring composite material of global significance is the wheat grain. The starchy endosperm makes up the majority of the grain.

The endosperm's dense structure must be broken down in order to produce food products like flour, which is accomplished by grinding the grains with strong forces [48].

The endosperm's fragmentation behavior has a significant impact on the amount and caliber of the milling products. This activity is highly dependent on the mechanical characteristics of the endosperm's constituent parts and how they interact because of its composite structure. Bran (15%), germ (3%), and endosperm (82%), together, make up the wheat kernel [48] (Figure 8).

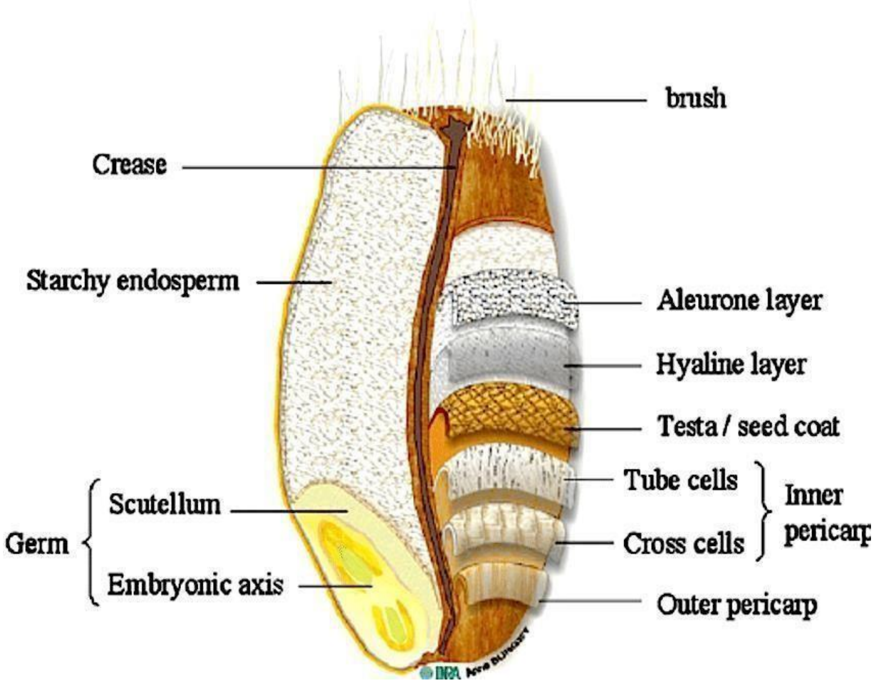


Figure 8. Histology of the wheat grain [48]

Amyloplast-formed starch granules are embedded in a protein matrix in the endosperm. About 25–28% of wheat starch granules are made of amylose. Based on size, the starch granules are classified as A-starch and B-starch granules, forming a bimodal distribution. B starch granules are small (2–8 μm) and spherical in shape, whereas A starch granules are big (20–45 μm) and lenticular [48].

Proteins and carbohydrates make up the endosperm's primary constituents. Proteins create a network (gluten) that envelops the starch granules, whereas carbohydrates are deposited as micrometer-sized starch granules. It is thought that some non-gluten proteins (puroindolines), whose presence and allelic status are genetically determined, have an impact on the interactions between proteins and starch. Grain hardness is low when puroindoline genes are present in the wild type form, and this has been linked to poor starch protein adhesion. The complete absence of puroindolines in the durum wheat species leads to very highgrain hardness and indicates a strong adhesion [48].

2.1.1. Wheat brain

There are two parts to the pericarp, or fruit coat, which envelops the entire seed: the inner and outer pericarps. The epidermis (epicarp), hypodermis, and deepest layer, known as the remnants of thin-walled cells, are the layers that make up the outer pericarp [48].

A natural plane of cleavage is formed by these thin-walled cells with a discontinuous cellular structure. Millers refer to the removal of the outer pericarp as "beeswing" because it facilitates the flow of water into the kernel. A single layer of cross and tube cells make up the intermediate cells that make up the inner pericarp next to the remnants [48].

The cross cells have a long axis that is perpendicular to the long axis of grain and are long and cylindrical, measuring roughly 125 × 20 µm. They have little to no intercellular space and are densely packed. The cross cells and tube cells are comparable in size and shape, but the tube cells' long axis runs parallel to the grain's long axis. There are numerous intercellular spaces because the tube cells are not densely packed and do not form a continuous layer. Only the mid-dorsal area of ripe grains exhibits them [48].

On the inside, the nucellar epidermis is securely attached to the tube cells, while on the outside, the seed coat (testa or integument) is the next layer inward. A thick exterior cuticle, a layer that is highly pigmented, and a thin inner cuticle make up the seed coat of red wheat. White wheat's seed coat is made up of cell layers with little or no pigment. The hue is associated with the pigment in the testa and is often red or white, though purple is also recognized. The perisperm and hyaline layer of the nucellar epidermis are closely attached to the inside of the seed coat. The seed coat has a thickness of 5 to 8 µm. The nucellar epidermis is tightly attached to the seed coat and the aleurone layer, and it is roughly 7 µm thick. It has been estimated that the entire pericarp makes up around 5% of the kernel volume [48].

2.1.2. The aleurone layer within the whole grain

A complicated structure made up of various tissues is the wheat grain (Figure 8). Because these layers serve a variety of purposes during the grain development, they have unique compositions and architectures. Roughly 80–85% of the grain is made up of the starchy endosperm, 12–18% of the bran, and 2-3% of the germ layers. Starch and proteins make up the majority of the endosperm, but the outer and germ layers contain the majority of the fibers, vitamins, minerals, and phytochemicals [3]. The outermost portion of the starchy endosperm is known as the aleurone layer in botany, and it makes about 5–8% of the wheat grain.

The miller, however, views the aleurone as a component of the bran since it remains affixed to the hyaline layer during the milling process and is thus separated from the endosperm.

The outer pericarp, inner pericarp, testa, nucellar epidermis (also known as the hyaline layer), and aleurone layer are among the adhesive tissues that make up the wheat bran portion, which is a composite multi-layer substance with some connected starchy endosperm remnants. Due to a high concentration of ferulic acid (FA) dimers, the outer and inner pericarps are made up of empty cells that are primarily constituted of branching heteroxylans, cellulose, and lignin. These cells have many cross-links between the polymer chains [3].

The testa is a lignin-rich hydrophobic layer that is distinguished by the presence of lipidic substances like alkylresorcinols in a cuticle at its surface [3]. Over 90% of the arabinoxylans in the hyaline layer are inadequately cross-linked. A single layer of live cells makes up the wheat aleurone layer (Fig. 8); in barley, rice, and oats, the layer is multilayered [48]. Aleurone cells in wheat have a diameter of 20–75 µm [3], and half of the wheat bran is made up of the aleurone layer. The thick, nonlignified cell walls that enclose the cytoplasm or intracellular media make about 35% of the volume of the aleurone cell. [3], and over 40% of the mass of the stratum. Aleurone cell walls are composed of 65% moderately linear arabinoxylan with a low arabinose to xylose ratio, high levels of esterified FA monomer, 29% β-glucans, and few proteins [3].

Numerous spherical particles (2-4 µm in diameter) known as aleurone granules are found in the intracellular medium of aleurone cells. These granules are encased in a thin layer of lipidic droplets and are either phytate inclusions (type 1: made of phytic acid minerals) or niacin inclusions (type 2: made of niacin and proteins) [3].

The nutrients in the aleurone layer are especially abundant. In fact, large levels of protein, minerals, phytates, B vitamins including niacin and folates, and lipidic substances like plant sterols are found in the intracellular medium of aleurone cells [3]. Aleurone contributes 30% of the total lysine, the first limiting necessary amino acid in wheat, and 15% of the total wheat protein [48]. The aleurone layer in wheat contains a significant amount of additional B vitamins and at least 80% of the total niacin. Overall, the aleurone layer contains between 40 and 60 percent of the wheat's mineral content, indicating a significant mineral supply [3].

2.2. Average composition

All things considered; the chemical makeup of wheat grain makes it a staple crop with a wide range of applications in different culinary products across the globe. Carbohydrates (70–75%), mostly in the form of starch, make up the majority of wheat grain. Protein (10–15%), lipids (1–2%), vitamins (including B vitamins), minerals (such iron and magnesium), fiber (2–3%), and water (10–15%) are the next most common components [49]. Regarding food processing, one of the most important factors influencing flour's baking quality is the GPC and starch content of wheat grains [50].

Gluten and other wheat proteins are important in influencing the dough's strength, elasticity, and extensibility, all of which affect the final quality of baked goods [43]. In order to create a well-risen and airy bread, the gluten proteins work together to build a strong, elastic network that traps the gasses that the yeast produces during fermentation. High GPC wheat types are typically used for breadmaking because they yield easier-to-work-with doughs and breads with superior volume, texture, and crumb structure. [50].

2.2.1. Wheat protein content

For all final products (uses of wheat), including bread baking, noodles, paste, cakes, and cookies, the protein level of wheat is a crucial factor. Wheat class, growing region, soil type and quality, and, of course, fertilizer input (amount and timing), particularly nitrogen, all have a significant impact on wheat protein content. Depending on the baking method, flour made from higher protein wheat has a better capacity to absorb water and, therefore, a bigger potential for bread volume. Wet gluten content and wheat protein content are closely related and are both utilized as quality indicators when buyers and sellers are negotiating wheat prices. Even while protein content is a selection criterion in breeding programs since it is an innate genetic feature, the environmental impact is far higher than what the breeders can manage [51].

However, protein quality, processing, and the link between protein and starch in particular in different food systems further complicate the quality of wheat and flour. We'll talk about a few of these later. Traditionally, wheat proteins have been categorized based on their solubility characteristics. Osborne created the first thorough separation system for wheat proteins in 1907) [51]. It was based on the different solubility of the proteins in various solvents [51]:

- Albumin: soluble in water.
- Globulin: soluble in salt solution.
- Gliadin: soluble in 70% aqueous ethanol.
- Glutenin: soluble in dilute acid or alkali.

Together, gliadin and glutenin make up around 80% of the proteins in flour and are found in roughly similar levels [50, 51]. The two most significant factors that determine wheat flour's functional qualities are gliadin and glutenin. A suitable balance between gliadin, which adds to dough viscosity, and glutenin, which adds to dough strength and elasticity, is necessary for optimal dough qualities.

The functional qualities of dough are made up of the special fusion of these characteristics. The gluten proteins are more crucial to the quality of bread than the albumin and globulin proteins [50].

Prolamins are storage proteins that dissolve in alcohol-water combinations. They have significant glutamine and proline levels, which combined make up 30–70% of their amino acid makeup [51]. A categorization based on primary-structure relationships has been developed by comparing the amino acid sequences of distinct prolamins.The three groups are [43, 50, 51]:

- High molecular weight (HMW) prolamins: the HMW glutenin sub units (HMWGS)
- Sulfur-rich prolamins: the low-molecular-weight glutenin sub-units (LMW-GS), α- gliadins, β-gliadins and γ-gliadins.
- Sulfur-poor prolamins: ω-gliadins.

2.2.2. Phenolic Compounds

Simple phenols, phenolic acids (ferulic acid (FA), p-coumaric acid, sinapic acid (3,5-Dimethoxy-4 hydroxycinnamic acid), syringic acid, vanillic acid), alkylresorcinols, and complex phenols (lignin and lignans) are the primary phenolic chemicals found in aleurone [52]. Soluble free acids, soluble conjugated moieties esterified to sugars and other low molecular mass compounds, and insoluble bound moieties esterified to arabinoxylans and other cell wall structural elements comprise the majority of phenolic acids found in wheat grains. While sinapic and vanillic acid are primarily found in the conjugated form (69% and 67%, respectively), FA and p coumaric acid are primarily found in the binding form (92% and 63%, respectively) [52].

Alkylresorcinols are another common simple phenol found in wheat grain, with amounts ranging from 280 to 1400 µg/g grain [52]. Since the consumption of whole grain wheat and rye is reflected in the plasma alkylresorcinol C17:0 to C21:0 ratio, the plasma total alkylresorcinol concentration seems to be a helpful biomarker of whole grain cereal intake [52]

2.2.3. Flavonoids

A variety of plant diets contain flavonoids, which are polyphenolic chemicals [53]. Epidemiological studies show an inverse relationship between their consumption and cancer, metabolic syndrome, coronary heart disease, and cognitive decline. In the Prainsin study [53], flavonoids and coronary heart disease were found to be significantly inversely correlated. However, nothing is known about the bioavailability of wheat flavonoids or their relative health benefits, and the role of wheat in these effects has not been studied.

Nevertheless, flavonoids may function as antioxidants by preventing LDL oxidation, chelating redox-active metals, and scavenging free radicals, according to in vitro research. By lowering platelet aggregation [53], suppressing the production of cell adhesion molecules, and regulating blood pressure and lipid profiles, flavonoids may prevent the atherosclerotic process. Mechanisms that lower the risk of cancer could include apoptosis-inducing qualities and anti-proliferative actions. Future research on wheat flavonoids is necessary to understand how wheat diets could contribute to these effects, as the combination of these pathways may partially explain the protective effects of flavonoids against chronic disease [53].

2.2.4. Lignans

Lignan is the name for a group of polyphenolic compounds that display mild phytoestrogenic activity [54]. Some of the metabolic activity linked to lignin consumption is caused by enterolignans, which are produced when gut bacteria ferment lignans and are then absorbed. Flaxseed, cereal brans, whole grains, legumes, seaweed, fruits, and vegetables are among the foods that contain lignan [54]. Compared to flaxseed, whole grain cereals, such as wheat, are a low source of lignan and only produce trace amounts of mammalian lignans in vitro [54]. However, because whole grains are ingested in larger quantities than flaxseed, they might account for a larger percentage of the total lignan consumption [54].

Enterolignans have been found to have inverse relationships with a number of chronic illnesses, such as a lower risk of cardiovascular diseases (CVDs) and some types of cancer, such as thyroid, breast, prostate, and endometrial. Because of their potent antioxidant activity, lignans may provide protection by preventing or postponing the formation of breast cancer cells and defending against lipid peroxidation. Other cancer sites may potentially be affected by anticancer actions. A study by ***Adolphe et al.,*** [54] suggests that wheat lignans may account for some of the protective effects of wheat fiber consumption against colon cancer.

2.2.5. Sterols

Phytosterols are chemically similar to cholesterol [55]. The majority of plant-based foods, such as fruits, vegetables, grains, legumes, seeds, and nuts, include them. Although grains have a lower sterol content than oilseeds, they are nonetheless regarded as a significant source of sterols and can account for up to 40% of daily intake due to their high consumption when compared to other plant sources [55]. Consuming plant sterols is associated with a lower chance of developing numerous cancers, including those of the breast, prostate, colon, stomach, and lungs, according to epidemiological research [55]. Phytosterols are well known for their cholesterol lowering properties.

According to meta-analyses, sterols and stanols can lower LDL cholesterol, suggesting that they may be used to treat blood cholesterol. ***Nurmi et al.,*** **[55]** demonstrated the efficacy of wheat germ phytosterols to reduce cholesterol absorption, at levels naturally present in wheat germ.

2.2.6. Fiber

The dietary fiber (DF) content of aleurone has been estimated to be 44–50 g/100 g DM **[56]**, depending on the wheat variety and purity of the aleurone fraction. The major polysaccharides present in the fiber fraction are arabinoxylan (65%) and β glucans (29%), while cellulose plays a more minor role **[56]**. α-L-arabinofuranose units are affixed to the linear β-(1, 4) linked xylan backbone of Arabinoxylans (AX) as side residues by α- (1, 3) and/or α-(1, 2) linkages. At O5, arabinose residues are esterified from ferulic acid or diferulate residues. Depending on their degree of polymerization, arabinose residue distribution, and branching, AX have incredibly diverse architectures **[56]**.

The physical characteristics of AX are greatly impacted by these structural differences. From the pericarp to the endosperm, the arabinose to xylose ratio (A:X) falls. Therefore, compared to acidic AX from the pericarp/testa, neutral AX from the aleurone layer and AX from starchy endosperm have less branching, which could hypothetically increase their solubility and digestion. However, the dietary fibers found in the aleurone layer are primarily insoluble because to the cross-linking of AX from the layer by diferulates (Figure 8) **[57]**.

Table 5. Phenolic acid composition of wheat grain, wheat bran, and wheat aleurone fractions (μg/g) [57]

	Whole Grain	Wheat Bran	Wheat Aleurone∗
p-OH Benzoic Acid	5.0	19.7	28.4
Vanillic acid	4.9–21	16.5	20.0
Syringic acid	13–18	57.2	90.3
p-Coumaric acid	15–28	130–162	160–288
Sinapic acid	60–81	115–276	269–353
Ferulic acid	399–870	4610–5670	6440–7980
Ferulic acid dimers	19–150	780–1550	360–950

∗Pure hand isolated aleurone or milling aleurone fraction from Buhler AG (70–90% aleurone).

2.2.7. Minerals and Vitamins

Vitamins and minerals are abundant in the pericarp, germ, and aleurone layer. Therefore, some of these vital elements are lost in refined grain products **[58]**.

The goal of enriching cereal-based foods is to replenish the vitamins (thiamine, riboflavin, niacin, and folic acid) and minerals (Fe and more recently Zn) that are lost during milling. Fortification of cereal-based foods is mandated by law in many nations. The mineral with the highest concentrations is phosphorus [58] (Table 6). Unfortunately, because the majority is linked to phytic acid, its availability is low. Because of its great binding capacity, phytic acid reduces the bioavailability of other cations. Because phytases are activated during sprouting and fermentation, phytic acid levels drastically drop. These procedures significantly increase the mineral's bioavailability [58] (Table 6).

Table 6. Mineral and vitamin compositions of cereal grains [58]

Nutrients	**Wheat**	
Minerals	***Hard***	***Durum***
Ca (%)	0.03	0.04
P (%)	0.35	0.51
Phytic acid (%)	0.97	
K (%)	0.36	0.49
Na (%)	0.04	
Mg (%)	0.14	0.17
Fe (ppm)	40.1	47.8
Co (ppm)	0.05	
Cu (ppm)	4.9	5.6
Mn (ppm)	40	33.5
Zn (ppm)	30.9	41
Vitamins		
Thiamine (mg per 100 g)	0.57	0.67
Riboflavin (mg per 100 g)	0.12	0.11
Nicotinic acid (mg per 100 g)	7.40	11.10
Pyridoxine (mg per 100 g)	0.35	0.43
Pantothenic acid (mg per 100 g)	1.36	
Biotin (mg per 100 g)	0.01	
Folacin (mg per 100 g)	0.04	0.04
Carotenes (mg kg− 1)	0.2	0.2
Vitamin E (mg kg− 1)	12.8	28

Cereals, with the exception of teff and finger millet, are generally poor sources of calcium. Certain food preparation techniques, such nixtamalizing corn to make tortillas, significantly raise calcium levels. This mineral has a high bioavailability in tortillas cooked with lime. Cereals are mostly sodium-free and regarded as a good source of potassium. Degermination, decortication, and milling diminish the amounts of magnesium, iron, zinc, and copper found in whole grains [58].

With the exception of B12 and cobalamin, wheat is also regarded as a significant source of B vitamins; however, vitamin C is absent from dried mature grains. The aleurone layer contains the majority of B vitamins. People who eat milled rice are more likely to contract beriberi, a thiamine deficiency disease that is endemic in Eastern and Southern Asia. About 10% of the thiamine found in brown rice is present in milled rice (Table 6).

Niacin can be produced from tryptophan and is present in both bound and free forms. Since the glycosidic bond that makes niacin inaccessible is alkali-labile, the bioavailability of niacin is significantly increased when maize is treated with alkali for the manufacturing of tortillas. In parts of Southern Africa where maize is the primary food supply, pellagra, which results from a niacin shortage, is common and causes rashes, diarrhea, and dementia [58].

2.3. Distribution of constituents in grain

The germ comprises only 2 to 3 % of the kernel weight. It contains the plant embryo and the scutellum [59]. The tissue of the embryo is structurally separate from the restof the kernel and can therefore disassociate readily during milling [59], depending however on the mill and the process. It is recovered in the "shorts" fraction 3.

The aleurone layer is a single layer of living cells, which separates the starchy endosperm and the germ from the outer layers [58]. It is rich in nutrients, such as minerals, vitamin B and protein [46]. Though the aleurone layer is botanically a part of the endosperm,it usually separates from the starchy endosperm together with the outer layers during milling [59]. The outer layers include the pericarp (inner and outer), testa and hyaline layer. They enclosethe starchy endosperm and germ and protect them against moisture and mold [59]. In milling terminology, these tissues together with the aleurone layer are known as the "bran" [59].The bran fraction comprises 14 to 16 % of the kernel weight [59].

An important structural property of the wheat grain in relation to milling is the presence of a crease, which folds the bran layers towards the inner kernel (Table 8).

Table 8. Distribution of the principal nutrients in wheat grain [59].

	Grain	Pericarp		Aleurone		Endosperm		Germ	
	%	%T	%G	%T	%G	%T	%G	%T	%G
Proteins	13.7	10	4.4	30	15.3	12	73.5	31	6.8
Lipids	2.7	0	0	9	23.6	2	62.9	12	13.5
Starch	68.9	0	0	0	0	82	100	0	0
Pentosans	7.4	43	35.1	46	43.8	1.6	18.3	7	2.9
Cellulose	2.8	40	87.1	3	7.6	0.1	3.1	2	2.2
Minerals	1.9	7	7-22	12	43-61	0.5	20-23	6	9-12
Niacin	-	-	4	-	82	-	12	-	2
Riboflavin	-	-	5	-	37	-	32	-	26
Piridoxin	-	-	12	-	61	-	6	-	21

T : % of nutrients in the specified tissue %

G :% of nutrients in the whole grain kernel.

For example, the protein% in the pericarp tissue (%T) amounts to 10%, which in itself contributes 4.4% to the total kernel protein

The rheological characteristics of dough are significantly altered when the sugar sucrose is present. Dough's consistency and toughness decrease when sugar is added, but its stickiness and extensibility are enhanced. Perhaps because sucrose's affinity for water prevents starch and gluten from absorbing water, the resulting dough protein networks take longer to unfurl [43].

Moreover, aliphatic and aromatic amino acids' nonpolar side chains would require more energy to become exposed in a sucrose solution. Therefore, it is necessary to elevate the temperature during processing in order for protein cross-linking to occur [61].

Sorbitol, a low-molecular-weight polyol and plasticizer, may significantly reduce the rate at which the gluten network degrades. The texture of the dough can be stabilized by strengthening the hydrogen bonding bonds within the gluten system, which in turn encourages the dynamic depolymerization and repolymerization of gluten protein molecules during processing and cooking.

When sorbitol was added in a suitable quantity (2%), it improved the viscoelasticity of dough and the tensile strength of gluten in a study. Additionally, it decreased the dough's hardness and springiness, the weight of the glutenin macropolymer (GMP), and the cooking loss of fresh noodles [61].

The relationships between carbs, glutenin, and gliadin during dough formation and the impacts on noodle properties require additional clarification, despite the fact that the effects of carbohydrates on noodle properties have been thoroughly studied [61].

2.3.1. Properties of wheat proteins

The unique bread making properties of wheat are generally ascribed to the viscoelastic properties of its gluten proteins [60]. Polymeric gluten proteins (glutenin) are elastic, but monomeric gluten proteins (gliadin) behave viscous. The polymeric structure of glutenin contributes significantly to its special flexibility. Several distinct high and low molecular weight glutenin subunits connected by disulfide bonds make up the extremely diverse collection of polymers that is glutenin. There are other polymeric proteins in wheat, even though glutenin is clearly the main one [60].

They might not be given enough credit for their role in breadmaking. However, differences in bread-making performance are largely determined by differences in the amount and quality of glutenin. The structural characteristics of several glutenin subunit classes are explained. Changes in glutenin's structure, size distribution, and subunit composition can all affect its quality [60]. It has long been recognized that wheat flour proteins have a critical role in the quality of bread, with both protein quantity and quality being significant [61].

Gliadin and glutenin, two prolamin groups that make up the principal wheat endosperm storage proteins, have been the subject of extensive research because they give doughs the viscoelasticity that is thought to be necessary for the quality of breadmaking [61]. A large portion of the variance in bread-making quality among wheat cultivars can be attributed to qualitative changes in their composition and characteristics. Glutenin is especially significant since it is made up of polymers whose subunits are connected by disulfide bonds [61].

As mentioned before, around 80% of the protein in wheat flour is gluten. Gliadin and glutenin are found in the soluble and insoluble fractions of gluten protein, respectively, based on how soluble the protein is in an ethanol water solution [62]. The glutenin and gliadin proteins have diverse functions during dough production due to differences in their structural compositions (Figure 9). Glutenins form polymers stabilized by inter-chain disulfide bonds, whereas gliadins are monomers and interactwith glutenin polymers through non-covalent forces, especially hydrogen bonds [62]. While gliadins act as plasticizers of the glutenin network, giving dough its viscosity and extensibility, it is generally accepted that glutenin proteins form the polymeric protein network that gives dough its cohesiveness and elasticity [62]. Despite the fact that there are several reviews [62] on high molecular weight glutenin, a comprehensive review on the structure and functionof gluten protein is lacking.

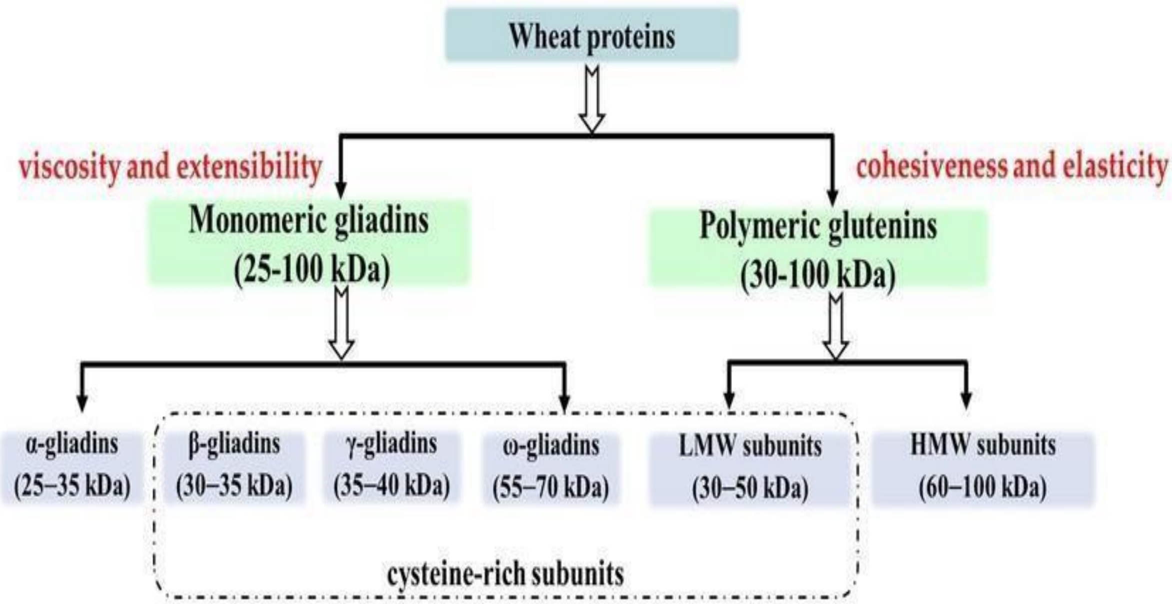


Figure 9. Classifications of wheat protein [62].

2.3.1.1. Glutenin

The massive macropolymers that make up glutenin, one of the biggest polymers in nature, are crosslinked by intramolecular or intermolecular disulfide bonds and contain high molecular weight (HMW-GS) and low molecular weight (LMW-GS) subunits (Figure 10B). The subunit masses of HMW-GS and LMW-GS make up roughly 20% and 80% of the total glutenin fraction, respectively, and vary from 60.000 Da to 100.000 Da and 30.000 to 50.00 Da, respectively, based on their electrophoresis mobility in SDS-PAGE [63]. HMW-GS mostly influence the final quality of dough.

a. High Molecular Weight Glutenin Subunits

The HMW subunits are encoded by genes located at the Glu-A1, Glu-B1, and Glu-D1 loci on chromosomes 1A, 1B, and 1D. Two genes in each locus encode the low-molecular-weight x-type subunit and the high-molecular-weight y-type subunit [63]. Six expressed HMW glutenin subunits should be present in hexaploid wheat, according to theory. Indeed, the composition of HMW-GS frequently differs amongst wheat cultivars as a result of allelic variation and gene silencing [63].

All cultivars typically have the 1Bx, 1Dx, and 1Dy subunits, although some cultivars additionally include the 1By and/or 1Ax subunits. As a result, certain HMW glutenin subunit compositions have been established as criteria for choosing wheat cultivars. The signal peptide (which is cleaved after maturation), the N- and C-terminal domains, and a central repeating region make up the basic structure of an HMW glutenin. These proteins' N- and C-terminal regions have highly conserved cysteine residues in terms of both number and location. There are 42 residues in the C-terminal domain between 81 and 104 in the N-terminal domain [63].

Repeats encoding tri, hexa and nonapeptides are the primary components of the repetitive domain. In x-type subunits, the repeat units are hexapeptides (PGQGQQ) and nonapeptides (GYYPTSLQQ), while hexapeptides (PGQGQQ) and nonapeptides (GYYPTSLQQ) make up the repeat units in y-type subunits [64].

Variations in the amount of tripeptides and hexapeptides are the main cause of differences in subunit size. These domains serve as the molecular foundation for the HMW-GS function. Interactions between the repeating domain and conserved cysteine residues, primarily disulfide and hydrogen bonds, preserve the higher order structure of the HMW glutenin subunits [64]. More crucially, the cysteines in HMW-GS are very important for the structure and function of gluten because interchain disulfide linkages promote the formation of gluten aggregates and are important for stabilizing HMW-GS polymers [64].

Scanning tunneling microscopy analysis of the repetitive structure of HMW-GS revealed that the non-repetitive N- and C-terminal domains are rich in α-helixes, while the reverse β-turns and β-sheet are arranged in a β-spiral structure [64]. According to reports, the strongest wheat dough was formed by HMW-GS with the most β sheets, and the highest β-turn concentration resulted in the greatest viscoelasticity [64].

b. Low-Molecular-Weight Glutenin Subunits

Low-molecular-weight glutenin subunits (LMW-GS) give dough special viscoelastic qualities that allow flour to be processed into a range of cuisines, as was previously described [64]. About 60% of the glutenins and 40% of the total storage protein in wheat grain are LMW-GS. Characterization of LMW-GS is more challenging than that of HMW-GS, primarily due to the mutigenic nature of LMW-GS and its poor solubility following the elimination of the intermolecular disulfide bonds. LMW-GSs typically have a 20 amino acid signal peptide (which is broken down after maturation), a 13 amino acid short N-terminal domain, a variable-length repetitive sequence, and a C-terminal domain made up of C-terminal I, C-terminal II, and C-terminal III [65].

According to the first amino acid res-idue of the N-terminal domain, LMW-GSs are classified into three groups, i.e., LMW-s (serine), LMW-m (methionine) and LMW-i (isoleucine). All genotypes examined have the highest abundance of LMW-s-type subunits, which have an average molecular mass of 35,000–45,000, higher than that of LMW-m-type subunits (30,000–40,000). As for the N-terminal amino acid sequence of LMW-s-type subunits, its sequence is SHIPGL.

On the other hand, the LMW-m type subunits, METSHIGPL-, METSRIPGL-, and METSCIPGL, have very different N-terminal sequences [64]. LMW-GS was initially discovered by separating wheat flour extracts from monomeric gliadins using gel filtration. Glutenin subunits can be separated into A (HMW-GS), B, and C groups based on their mobility in SDS-PAGE (LMW-GS) [65].

According to their structural properties, the C-type subunits operate as chain terminators of the elongating polymer by generating an intermolecular disulfide bond with only one cysteine, whereas the B-type subunits extend the expanding polymers by forming two intermolecular disulfide bonds [65].

New low-molecular-mass protein classes have been identified more recently. Anderson discovered a novel wheat endosperm protein that has a lot more cysteine residues, a significantly smaller central repeating domain, and unique N-terminal sequences [65].

Ikeda et al., [65] were successful in creating a particular PCR to differentiate 12 sets of LMW-GS genes. LMW-N13 is the biggest LMW-GS that was found in Aegilops uniaristata. An additional cysteine residue is also present. Transgenic wheat that overexpresses LMW-N13 has shown improved dough qualities. Meanwhile, capillary electrophoresis and RP-HPLC were utilized to fully identify LMW-GSs encoded by Glu-3 loci alleles.

The best quality parameters were found in wheat varieties with the Glu-3 loci scheme [65]. Low-molecular-weight glutenin subunits' crystal structure has been determined in much more recent studies on celiac disease, which is brought on by an immunological reaction to cereal gluten proteins [65]. It has been observed that, in contrast to gliadin, glut-L1 binds to the TCR generated from patients with celiac disease (Figure 10B).

Further characteri-zation of LMW-GS is highly needed to elucidate their rolein the formation of the gluten network and in human health [65].

2.3.1.2. Gliadin

Gliadins are monomeric proteins that give dough its sticky and foamy qualities. Five amino acids make up the single-chained polypeptide gliadin, which has molecular weights varying from 25 to 100 kDa and dissolves in 70% ethanol. Based on their genetic information and electrophoretic mobility, gliadins are categorized as α (25–35 kDa), β (30–35 kDa), γ (35–40 kDa), and ω (55–70 kDa) [66].

A hydrophobic center region that is rich in glutamine and proline and a terminal hydrophobic part that encircles the central hydrophobic area and is rich in hydrophobic amino acids are the two main domains that typically make up the gliadin structure. The water solubility of gliadin is typically limited; however it rises at very low pH levels. Its hydrophobic interactions and persistent disulfide bonds may be the reason for its poor aqueous solubility [66].

Thus, various extraction methods have been used to isolate gliadin. ***Sardari et al.,*** [66] tried to sequentially use different solvents, such as NaCl, ethanol and an alkaline solution, to isolate the albumin, globulin and prolamin fractions. Crucially, it has been demonstrated that the ratios of gliadin and glutenin can alter the rheological properties and functionality of wheat protein. After being hydrated, gliadin turns into a viscous liquid, giving dough its extensibility and viscosity [66].

2.4. Wheat technology at the factory

2.4.1. Processes before the milling

2.4.1.1. Pretreatments

In order to improve tissue dissociation, wheat bran and grain in general can be prepared prior to milling. The bran's biological activity and biochemical characteristics can also be altered by the circumstances of some repeated pretreatments. Tempering, which raises the moisture content, is the most popular pretreatment. As a result, the bran becomes more extensible, making it easier to separate from the starchy endosperm during the milling process [69].

Enzymes (cellulose, xylanase, beta-glucanase) or chemical agents (sodium chloride) may be present in the water used for tempering. Wheat bran's physical and biological characteristics may alter as a result of these activities [69]. According to ***Nuria Mateo et al.,*** [70] The concentration of extractable pcoumaric acid rose when sodium chloride was added to the tempering water. This was thought to be caused by changes in the cell-wall polymers that made the bran's phenolic acids more accessible.

It is possible to do physical pretreatments in addition to tempering. Ozone treatment, infrared radiation, and ultraviolet radiation are examples of physical pretreatments. Peyron et al. have examined how UV light affects the composition of wheat bran [71]. The ferulic acid monomer and the dehydrodiferulic acid ester connected to the cell wall arabinoxylans decreased by 25% and 44%, respectively, after 48 hours of UV exposure. The notable rise in ferulic acid (30%) and dehydrodiferulic acid (36%), which are involved in hot alkali-labile couplings, was partially explained by this decrease [71].

The bioaccessibility of ferulic acid from the wheat bran matrix may be impacted as a result of the induction of these linkages. These techniques have been primarily investigated to increase the flour output, which is why flour is extracted from the bran during milling, even if they may have an impact on the bioaccessibility of bioactive chemicals from the bran matrix.

2.4.1.2. Germination

Germination is the process in which the plant emerges from the seed. During germination important nutrients, such as dietary fiber, minerals and phytochemicals, located in the bran and germ are reported to increase [72]. Additionally, sprouted or germinated wheat has higher levels of phenolic chemicals. Alcohol extracts from sprouted wheat flour showed higher levels of phenolic chemicals and antioxidant activity, which were correlated with the duration of germination.

Caffeic acid and syringic acid increased from 1 to 3.8 mg g^{-1} and from 194 to 369 mg g^{-1}, respectively. Also, other phenolic acids, such as ferulic acid and vanillic acid, increased their concentrations with increasing germination time from approximately 600 to 900 mg g^{-1} and from 6 to 14 mg g^{-1}, respectively, as well as b-carotene from undetectable levels to 3 mg g^{1}, and a-tocopherol from 4.4 to 10.9 mg g^{-1} and g-tocopherol from 0.9 to 1.5 mg g^{-1} [72].

In germinated rye, besides the higher levels of folates, plant sterols and benzoxazinoids were also increased from 88 to 114 mg /100 g and from 6.4 to 53 mg/100 g, respectively [70]. Wheat sprout extracts were able to effectively inhibit DNA oxidative damage in vitro, which was attributed to the presence of glycosylated antioxidants.

During germination an increased activity of hydrolytic enzymes, such as xylanases, arabinofuranosidases, b glucanases, proteases and xylosidases, has been reported [73].

The bran matrix will undergo hydrolytic changes as a result, releasing nutrients and bioactive substances that are essential for plant growth. Additionally, this could lead to increased bioavailability and bioaccessibility. In fact, bread enhanced with wheat sprouts showed an increased bioavailability of phenolic chemicals.

A increased bioavailability of the phenolic compounds from the wheat sprouts was linked to the enhanced bread's ability to reduce blood sugar and increase plasma antioxidant capacity after nine days of consumption [73].

2.4.1.3. Debranning.

The process of debranning involves successively removing the bran layers through abrasion and friction. It was first employed as a cleaning agent to get rid of the grain's outermost layers, which had little nutritional value and large concentrations of impurities including bacteria and heavy metals [74]. Debranning to a removal of 4% of the wheat grain weight reduces the total microbial contamination by more than 80% [74]. Grain fractionation has recently drawn attention to debranning techniques. Peeling and pearling are the two most popular methods of debranning. In pearling, the bran is removed by abrasion of the wheat kernels against an abrasive stone, but in peeling, the bran is removed by friction of the wheat kernels through the machine and against one another. By varying the debranning time, the extent of removal can be managed. The maximum phenolic concentration and antioxidant capability are found in the pearling fractions obtained from removing 5 and 10% of the wheat kernel's bran [74]. Thus, reducing the amount of bran removed will lessen the amount of beneficial chemicals lost. According to this logic, since bran removal accounts for up to 3–4% of grain weight, and pearling accounts for 6–10%, the peeling process can be more fascinating than the pearling process [70].

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In fact, the ferulic acid content and antioxidant capacity of the flours made from peeled wheat kernels were higher than those made from pearled wheat kernels [70]. This is explained by the fact that peeling and debranning remove less of the kernel's outer layers, leaving the aleurone layer mostly intact [74].

The wheat grain's highest antioxidant capacity is found in the aleurone layer, which covers the endosperm and is often removed along with the bran portion during milling. There was a considerable correlation between the ferulic acid level and antioxidant capability of various wheat fractions and their aleurone content [74]. Therefore, it is important to preferably preserve the aleurone content during the manufacturing of healthy cereal products [72].

2.4.2. Grain milling

In simple words, milling is the process of removing the bran and grinding wheat into flour or semolina. The first step in the milling process is the cleaning of the grains with the aim of removing foreign material (straw, dust, soil, sand), molds and bacteria [75]. Following this cleaning process, which is typically accomplished by polishing, a debranning pretreatment may be used prior to tempering. After that, the grain is ground in a roller mill for processing. The technique of milling wheat is used to make the grains smaller. The milling machine uses rolling, friction, shearing, and extrusion to smash the wheat grains. The mill rolling distance (Figure 10), grinding roll speed, and fast/slow roll speed ratio are other crucial operating factors that impact the effectiveness of flour production and the quality of the flour after the raw material and its feeding quantity have been established [69].

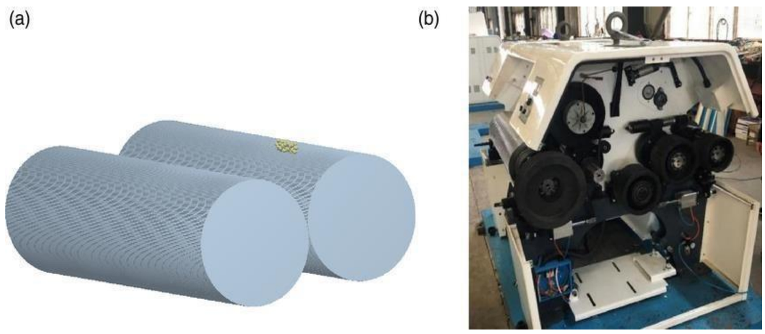

Figure 10. 3D geometry model of grinding rollers [69].

(a) Three-dimensional discrete element model; (b) Internal structure diagram of the mill.

The efficiency of separating the endosperm from the bran in the succeeding process is determined by the first crushing of the wheat, and this has a significant impact on the extraction rate and quality of other flour **[69]**. The endosperm of the wheat is finely ground to powdered direct packing or by joining the processing such as powder, making the final flour of various different brackets and purposes. The entire process of byproduct is known as the wheat flour milling technological process. This is accomplished with equipment such as grinding, shock, screen, and clear powder by the endosperm of the wheat after it has been cleaned out and Mai Pi and germ separation. In the whole grain wheat cleaning workshop, the technological process is referred to as the "cleaning technology flow process between wheat." Mai Lu: According to the powder process workshop, the brief mill diagram is a technological procedure between powders. The current mill diagram is separated into five distinct powder systems (operations): shelling, sizing, reduction, tail rolls, and clear. Shelling results in the removal of wheat, the scraping of large granular endosperm, the extraction of as much coarse grain meal (industry jargon says "slag making") that improves the quality of the extracted material, and the retention of as much endosperm as possible under the condition that the bran flakes are complete. The most crucial piece of equipment in a wheat flour milling business is the flour mill, and its most crucial component is the grinding roller, often known as a roll. According to arts demand, The two main categories of grinding rollers are the fluted descaling roll, also known as the roll surface cutting roll, which is used to strip off wheat and scrape in order to obtain endosperm particles, and the roll surface, which is a smooth, level roll that is used to create flour by finely rounding endosperm particles. the grinding roller of nations currently producing goods worldwide. It is made of high-quality quench alloy cast iron with anti-wear properties. In addition to extending the grinding roller's service life and reducing the need for replacements, improving the flour mill's service life, and stabilizing and enhancing the powder process's technological impact, it can also increase output, quality, flour extraction, and reduce the amount of energy. Wheat is one of the major grains worldwide, which providesnearly 20% calorie and protein per capita worldwide **[67]**. The technological process of wheat milling is called “flour road.” Eight milling parts can be obtained after wheat milling, including six flour parts [i.e., three “broken” (B) and three “reduced” (R) milling parts] and two kinds of bran parts (i.e., bran and shorts). The flour collected by B_1, R_1, B_2, R_2, B_3, and R_3 is standard flour; that by B_1, R_1, B_2, and B3 is bread flour; and that by B1 and R1 is refined flour **[68]**. Grain fragmentation into tiny pieces is the result of milling. This procedure separates the bran and germ from the white flour, usually by sieving, and is often based on particle size. (mainly endosperm). ***Borrelli et al.,*** **[75]** shows that the content of a-tocopherol in flour decreased by 60% when increasing the time from30 to 180 s of milling of the wheat kernel. After milling, 43%, 67% and 20% of thiamin, riboflavin and pyridoxine were recovered in white flour, compared to 80%, 100% and 95% in reconstituted whole wheat flour, respectively [75].

Additionally, milling wheat grain reduces the amount of phenolic acids and semolina's antioxidant activity. Therefore, the traditional milling method will significantly lower the concentration of other beneficial components that are mostly found in the bran [75].

2.4.2.1. Bran fractionation

The two stages of bran fractionation are separation and fragmentation. The bran tissues are ground down and/or separated during the fragmentation process. The force placed on the bran varies depending on the fragmentation technique (impact, shearing, compression, crushing, etc.), producing particles with various characteristics. The bran particles are separated in the separation step based on a number of characteristics, including size, shape, mass, density, and dielectric characteristics. Numerous separation techniques exist, including the commonly used sieving and air-classification techniques as well as more cutting-edge techniques like electrostatic separation, which will be covered in more detail [70]. Another method worth mentioning is the fragmentation process of cryogenic ultra-fine grinding, which has been investigated by Hemery et al., [69]

2.4.2.1. Ultra-fine grinding.

The goal of ultra-fine grinding is to make the bran bits smaller. This procedure is known as cryogenic grinding when it is carried out at low temperatures below 0°C (-10°C to -140°C). Liquid nitrogen is utilized to chill this procedure. It has been proposed that cryogenic grinding facilitates particle fragmentation and may prevent thermolabile chemicals from degrading [76]. A decrease in particle size may facilitate solvent compound interactions and their extractability and bio accessibility. In this manner, the ultrafine grinding may increase the bio accessibility and bioavailability of bioactive compounds from the wheat bran. Hemery et al. [69] showed that In fact, in a gastrointestinal model, the bioaccessibility of ferulic acid and sinapic acid as well as the overall antioxidant capacity of the bioaccessible fraction from bran-rich breads increases when the size of the wheat bran particles decreases [74].

2.4.2.1.Electrostatic separation.

The process of electrostatic separation involves first applying an electric charge to the bran particles, and then, based on the charge that has been obtained, separating the charged particles in an electric field. The effects of electrostatic separation after ultrafine grinding of bran have been recently investigated by ***Hemery et al.,*** **[69]**. The bran particles might be divided into three portions through the electrostatic separation process: a less charged fraction, a positively charged fraction, and a negatively charged fraction. Because aleurone and pericarp cell walls charge differently, these fractions have diverse histological and biochemical compositions.

The complex heteroxylans of the pericarp are known to be characterized by the presence of dimers and trimers of ferulic acid, galactose, arabinose and thus arabinoxylan, and the negatively charged portion, which is richer in the outer pericarp **[77]**. The less charged fraction had the highest concentration of alkylresorcinols, which are known to be found in the testa, since it had a larger percentage of intermediate layers, such as the inner pericarp, testa, and hyaline layer **[77]**.

The positively charged fraction was richer in folates and phytates because of its large proportion of intracellular aleurone, and it had greater levels of b-glucans and ferulic acid monomer because of its high content in aleurone cell walls **[77]**.

With a median particle diameter of 26.5 mm and 77% of the particles below 50 mm, the positively charged fraction had the smallest particles, which were also abundant in free intracellular aleurone contents and tiny cell wall fragments. The biochemical makeup varies among the fractions in addition to the diversity in particle size distribution, which affects the bioaccessibility of substances as previously mentioned. The biological composition of the fraction could be connected to their charging behavior. There found a positive correlation between the particles' charge and ferulic acid concentration **[78]**.

For instance, the most positively charged fraction obtained with this method by Hemery et al. **[69]** represents 34% of the bran and contains 62% of the ferulic acid content in bran. Furthermore, when bran-rich breads were examined in an in vitro gastrointestinal model, the bioavailability of ferulic acid, sinapic acid, and p-coumaric acid was higher from the breads made with the positively charged fraction (3%, 40%, and 12%, respectively) than from the breads made with bran (2.5%, 27%, and 6%, respectively) **[73]**.

2.4.3. Processes after the milling

2.4.3.1.Bread making.

For eons, bread has been a widely consumed staple food. Thus, one of the most thoroughly studied processing methods in cereal technology is the bread-making process (Figure 11). Baking, fermenting, and mixing are its three main phases [78].

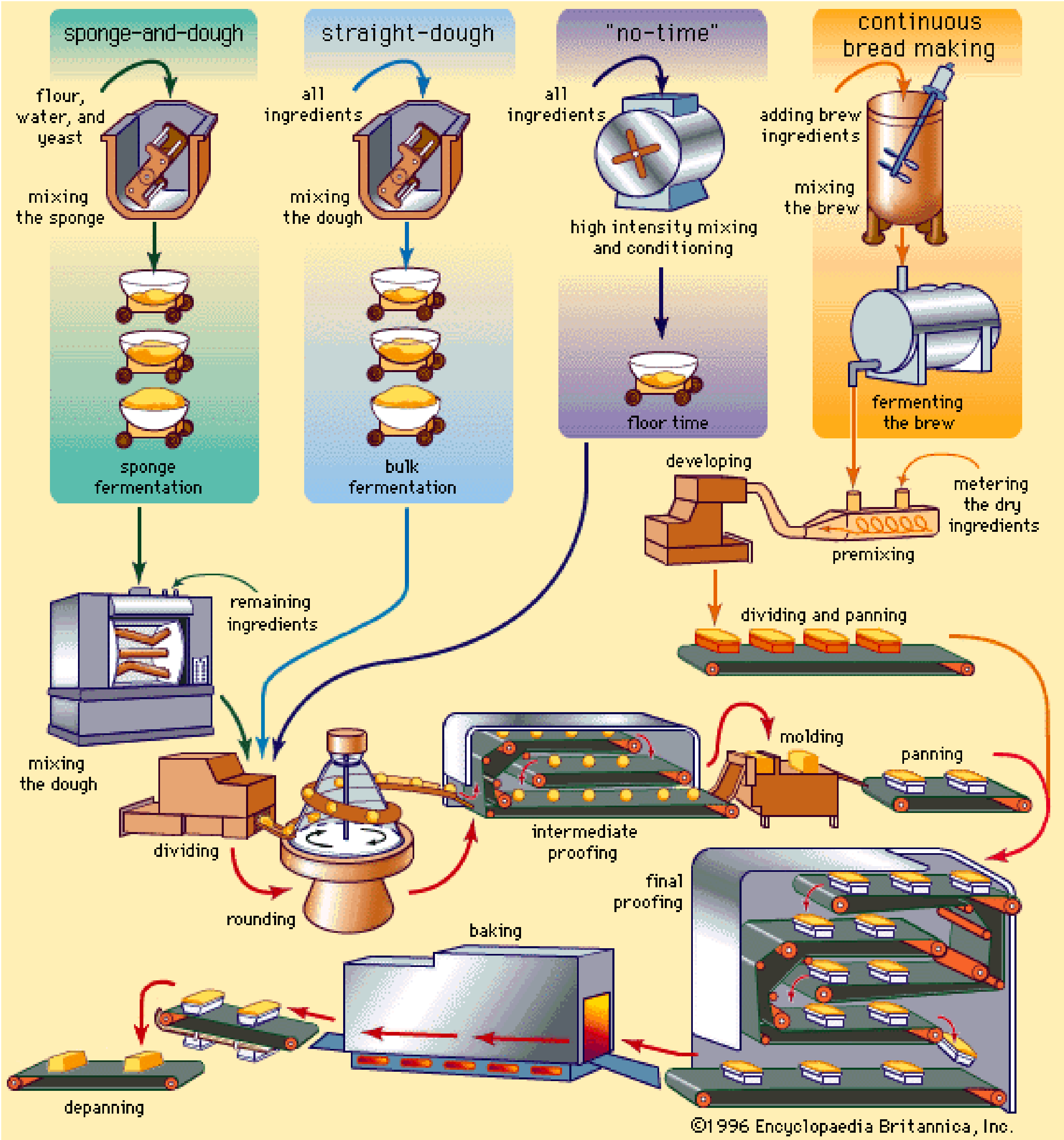

Figure 11. The process of bread making [78]

The stability of certain bioactive substances, such phenolic compounds, can be decreased by heat processing, like in bread baking, and kneading (mixing), when oxygen comes into contact with labile molecules [78]. It has been noted that substantial losses of tocopherols and tocotrienols occur during the kneading process used in the production of bread and pasta [78]. According to reports, lipoxygenase-catalyzed enzymatic oxidation or direct oxidation are the primary causes of tocopherol loss [79].

By limiting oxygen incorporation, a prolonged fermentation period for the dough may result in a reduction in kneading time and intensity, which may preserve carotenoids and vitamin E [79]. The lutein level is significantly reduced (37–41%) when bread is baked. The influence of thermal processing on possible health benefits was assessed by evaluating the antioxidant activity of purple wheat bran, heat-treated purple wheat bran, and purple wheat bran muffins. ***Hidalgo et al.,*** [79]. The conditions selected for heat treatment did not markedly change the antioxidant activity of purple wheat bran.

However, when muffins made with purple wheat bran or muffins that were heat-treated with purple wheat bran were processed, the total phenolic content, oxygen radical absorbance capacity (ORAC) values, and total anthocyanins were significantly reduced. Quite the opposite; muffin extracts continued to exhibit outstanding 2,2-diphenyl1-picrylhydrazyl (DPPH) radical scavenging efficiency [79]. Baking often results in smaller losses than boiling, which can cause losses of about 40% for most B-vitamins and somewhat larger losses of folate [80]. Due to their inability to withstand heat (baking) and oxygen (kneading), 31% of thiamin and 37% of pyridoxine were lost throughout the bread-making process in whole bread and 37% and 62% in white bread, respectively. Additionally, about 25% of folate is lost when bread is baked [80].

The action of phytases in the dough and the heat during the bread-making process cause the amount of phytic acid to decrease. Cereals, yeast, and lactic acid bacteria that were separated from sourdough all include enzymes that break down phytotate. One benefit of bread baking's hydrolytic impact is that it may increase the bioavailability of minerals like iron, calcium, and zinc, which phytate often inhibits [75].

Surprisingly, extending the wheat dough's baking duration from 7 to 14 minutes and raising its temperature from 205 to 288°C increased its antioxidant qualities by 60 and 82%, respectively, according to several radical scavenging techniques [81].

This increase, however, could not be explained by an increase in the concentrations of soluble free or conjugated ferulic acid [81]. It might therefore be a result of the formation of Maillard reactive compounds that have been reported to show radical scavenging activities [81].

Likewise, raising the baking temperature improves the phenolic antioxidant content (measured in gallic acid equivalents) of the white bread crust and the antioxidant qualities of whole-wheat pizza crust, most likely as a result of the Maillard reaction products [81].

2.4.3.2. Fermentation.

In food, fermentation is essentially the anaerobic process by which bacteria transform carbohydrates into alcohols, carbon dioxide, or organic acids. There are two primary systems for fermentation processes: solid state fermentation, which is any fermentation process carried out on a non-soluble material that serves as a source of nutrients and physical support in the absence of free-flowing liquid, and submerged fermentation, which is based on the cultivation of the microorganisms in a liquid medium containing nutrients. The moisture content of the substrate ranges from 40 to 80% to support the growth and metabolism of microorganisms [82].

Bioactive substances are created by microorganisms as secondary metabolites following the completion of microbial development through solid state fermentation. For example, the phenolic content and antioxidant qualities of wheat grains were significantly enhanced by the employment of two distinct filamentous fungus (*Aspergillus oryzae* and *Aspergillus awamori*) in SSF. When compared to non-fermented wheat grains, fermented wheat grains were thought to be a healthier and more antioxidant-rich food supplement [82]. The most common fermentation processes in bread making are yeast fermentation and sourdough.

Yeast produces carbon dioxide during the bread fermentation process, which causes the dough to rise and expand in volume a process known as proving. Sourdough bread is made with lactic acid bacteria in addition to yeast, which increases the acidity of the finished product [78].

a. Yeast fermentation.

Yeast fermentation is a regular treatment in the standard process of bread making. The most commonly used ferment is Baker's yeast consisting of *Saccharomyces cerevisiae* [69].

The riboflavin concentration in wheat bread rose by 30% when a long yeast fermentation of 360 minutes was substituted for the traditional 90-minute fermentation in whole bread manufacturing, indicating a possible synthesis or benefit from the ferments utilized [78]. Similar to this, yeast makes up for the folate lost during bread baking by both generating folates and maintaining a high intrinsic folate concentration [82]. However, the fermentation process reduces the amount of several other B vitamins. The bread-making process resulted in a 47% pyridoxine and a 2-35% thiamin depletion [70].

However, using longer fermentation times the thiamin levels became similar to the original ones [70]. In the study by ***Jung et al.,*** [83] solid state yeast treatments increased the phenolic acids, total phenols and the antioxidant capacity of the wheat bran extracts determined by various methods (ORAC, TEAC, DPPH, and hydroxyl radical scavenging).

Longer fermentation periods of 18 to 48 hours considerably enhanced the wheat dough's antioxidant capability in a subsequent investigation conducted by the same authors. For example, a 25–27% increase in hydroxyl scavenging activity was linked to a 75–130% rise in soluble free ferulic acid over 48 hours of fermentation [83].

b. Sourdough.

Sourdough bread baking consists of a fermentation process by a mixture of yeasts and lactic acid bacteria. This fermentation is usually at ambient/moderate temperatures for around 16–24 h [84]. There are several ways that modifications to the grain matrix could result in better nutritional content. These include producing acid, which is thought to slow down the digestion of starch, and adjusting pH to a range that supports the activity of specific endogenous enzymes. Proteins and fiber are hydrolyzed and dissolved by the action of enzymes during fermentation, which may have an impact on the bioavailability of minerals and phytochemicals from the food matrix. This is particularly advantageous for bran-rich goods because it allows the blood circulation to carry bioactive and perhaps protective compounds [84].

The effects of fermentation by the yeast Saccharomyces cerevisiae and two lactic acid bacteria *Lactobacillus rhamnosus* on the antioxidant properties and total phenolics of buckwheat were assessed and contrasted with those of their unfermented counterparts. Antioxidant activities (DPPH, FRAP, and TBA) and total phenolic content were improved. Therefore, one way to further boost the bioactive potential of grain products is through fermentation [84]. Conversely, the action of phytases during sourdough baking lowers phytate levels, increasing the bioavailability of minerals [84]. However, there are certain unfavorable impacts of sourdough on the levels of certain bioactive components when producing bread.

Tocopherols and tocotrienols are reduced by 20–60% [80]. Additionally, when baking sourdough bread, the amount of pyridoxine is reduced by roughly 20% in comparison to the original flour. The B vitamins thiamin and riboflavin, on the other hand, maintain their initial levels, although thiamin is lost after regular baking. Additionally, sourdough fermentation raises the amounts of free ferulic acid, readily extracted total phenolics, and folates [82]. There are several health benefits associated with sourdough bread in addition to the impact on the bioactive ingredients mentioned above and their bioavailability from the wheat bran. Processing has previously been proposed. For example, eating sourdough wheat bread may reduce insulin resistance participants' postprandial glucose and insulin responses [84].

2.4.3.3. Enzyme technology.

Many of the wheat bran bioactives occur bound to fiber or protein, and trapped in the aleurone cells. This is the case of the phenolic acids that are covalently bound to cell wall polysaccharides, mainly to arabinoxylans (AX) [85]. The backbone of AX is composed of b-(1,4)-linked xylose residues, which can be bound to arabinose residues on the $C(O)_2$ and/or $C(O)_3$ position. Ferulic acid can be esterified on the $C(O)_5$ position of arabinose [85].

Most of the ferulic acid in wheat bran is bound to AX, which limits its bio accessibility and bioavailability from bran rich products. There are numerous enzymes targeting specific linkages of the arabinoxylan structure. Endo-b-(1,4)-D-xylanases cleave the xylan backbone internally, b-D-xylosidases remove xylose monomers from the non-reducing end of xylo-oligosaccharides, a-L-arabinofuranosidases remove arabinose substituents from the xylan backbone, and ferulic acid esterases remove ferulic acid groups from arabinose substituents [85].

Therefore, strategies that involve the use of these and other enzymes are likely to cause a food matrix restructure that facilitates the release of the embedded compounds, such as ferulic acid. Furthermore, a synergy in the enzymatic release of ferulic acid from wheat bran has been reported for ferulic acid esterase and xylanases, which makes the combination of these enzymes an interesting approach to improve the ferulic acid bioaccessibility [85]. It has been observed that treatment of wheat bran insoluble dietary fibre with xylanases released feruloylated oligosaccharides from the bran and feruloyl oligosaccharides have been reported to protect against oxidative DNA damage in normal human peripheral blood lymphocytes [85].

Treatment of wheat fiber with the hydrolytic enzymes (mainly 1,3-b-glucanase and xylanase activites) of Tricoderma produced an increase in the soluble fiber as well as a 4-times increase of the water extractable ferulic acid. In another study with wheat grain treated with the fungi *Aspergillus*, a positive correlation was found between the phenolic content of the wheat extracts and the activities of the hydrolyzing enzymes a-amylase, b- glucosidase and xylanase [85].

Five commercial food-grade enzyme preparations with documented enzyme activities, including cellulose, polygalacturonase, aminopeptidase, b-glucanase, and various side activities, were examined on wheat bran by Moore et al. Half of the insoluble bound ferulic acid was liberated into its soluble free form, which is the bioavailable form, by the most effective enzyme preparation (mostly b-glucanase activity).

The enzyme treatment also liberated other bound phenolic acids, including p-coumaric acid and hydroxylation of syringic acid. When fermentation and hydrolytic enzymes were added to the bran, the amounts of these colonic metabolites of ferulic acid increased [85]. The in vitro results obtained with the intestinal models described above have beenconfirmed in vivo by a follow-up study in humans by the authors.

Participants in the cross-over postprandial study had to eat 300 g of either wholegrain bread with wheat bran or wholegrain bread with bioprocessed wheat bran as part of the human trial. Similar to the above-described in vitro investigations, the bran was bioprocessed using a combination of hydrolytic enzymes and yeast fermentation. The bread's bioavailability of ferulic acid and other phenolic components was enhanced by a factor of 2.5 by the bioprocessing of wheat bran. In an ex vivo LPS-induced inflammatory response, this may also be linked to an increase in the anti-inflammatory potential [85].

2.5. Equipment used at the cereal factory

Following its arrival at the mill, the wheat that is going to be ground is cleaned. A screw conveyor is used to move the wheat from the silos to the mill after it has been weighed. It then passes through a separator to remove large impurities, a destoner to remove small pebbles and stones, a round seed sorter to remove broken wheat grains and round seeds, and finally a long grain sorter. [58]. The purified wheat then rises toward a wetting screw with the aid of an elevator to undergo humidification, the rate of which is determined by its initial humidity. It then moves on to the first rest, which lasts for 48 hours, and the second rest, which lasts for 24 hours. These wetting stages and rest periods are known as wheat conditioning implemented, and they are dependent on the flour's extraction rate and the quality of the final products. Proper packaging maximizes grinding [63]. The wheat undergoes three stages of transformation after being watered and allowed to rest in clean wheat bushels for 24 to 48 hours (Figure 12), which are [57]:

Grinding: works using fluted cylinder devices.

Breaking: its role is to reduce the semolina operated by smooth cylinders to grind them particles even more finely.

Conversion: final operation of several passes in a series of smooth cylinders for obtain fine products down to flour cylinder

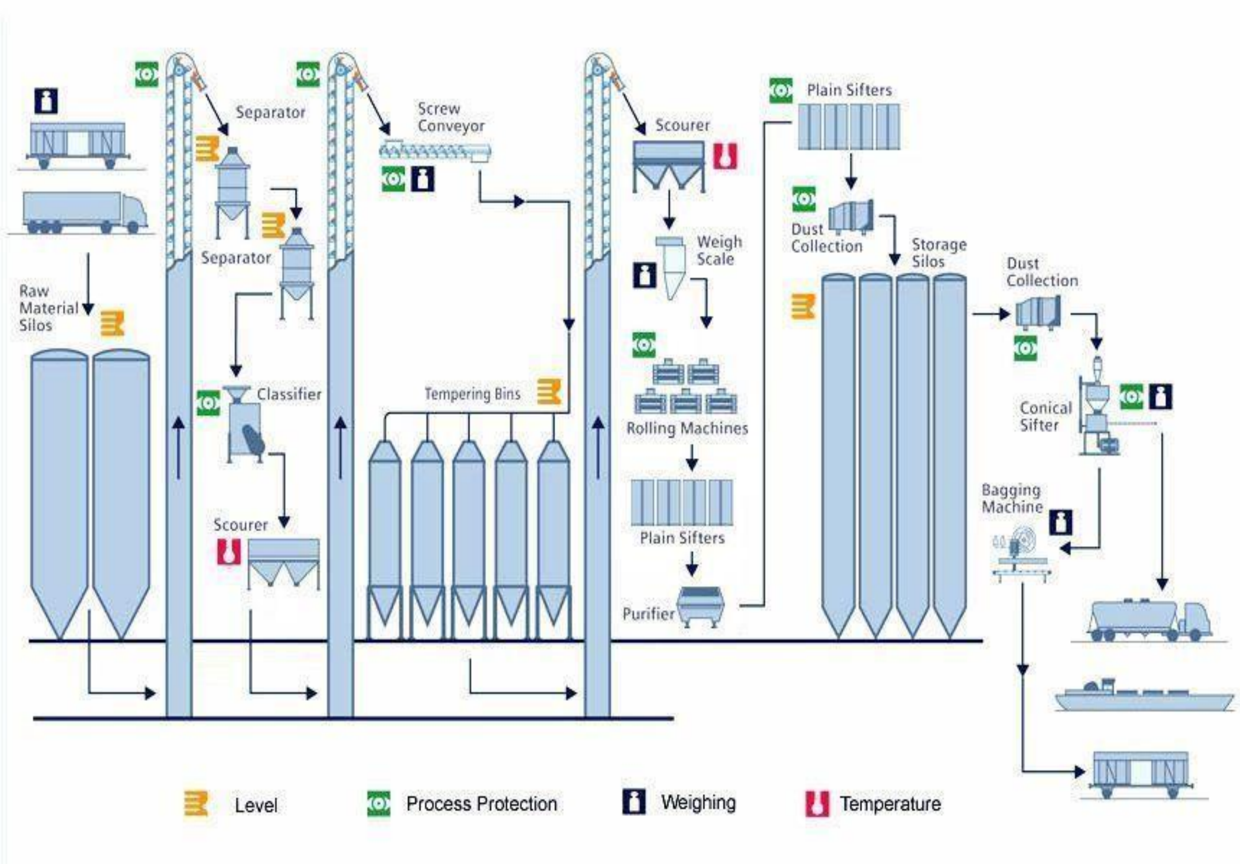

Figure 12. Flour Milling/Grinding Machine for Flour Production Processing [59]

There are different types of crusher such as:

a. Knife grinders

They employ a rotor-stator system to shear the crushed product; they are also referred to as granulators. Aside from the power supply (about 250 at 1500 Watts), their production capacity is also dependent on the rotor's speed, the length and quantity of knives, as well as their shape. In addition to processing plastics and paper, these devices are especially advised for processing fibrous materials including vegetables, aromatic plants, and some spices. The resulting sizes are typically between 1 and 6 mm. The flow rates can be quite high, exceeding several tens of tons per hour, as demonstrated by the crushing of beets in candy. Certain devices can introduce huge pieces since they have power supply devices [59].

b. Ball mill

The body of the ball mill is composed of tubular metal. The loads inside the drum are called grinding bodies, and they are composed of spherical metal balls with a well-defined diameter and a hardness that is comparatively higher than that of grinding ores. Using a drive motor, the entire apparatus revolves around an axis parallel to the cylinder's [59]

c. Hammer mills

Are used to grind hard materials such as stone, rock or glass [59]

d. Roller mill

The primary body of the crusher, which is commonly employed in the grain processing industry, is made up of two fluted cylinders. The product is transported to the distributor roller via the metering roller after the grains to be processed arrive by gravity into the hopper feed. As a result, this product is dispersed evenly at various speeds along the whole work area. A pipe beneath the cylinders evacuates the ground product. Roller mills grind wheat well and produce a lot of grain [59].

The cylinders' measurements are as follows: Length: 1000, 1250, and 1500 mm; diameter: 250 and 300 mm. Consistency during grinding is one of the mechanical requirements of grinding cylinders. On More's apparatus, the dynamic method, whose unit is (HOR), is used to determine the hardness of these cylinders. The average hardness of the fluted cylinder's working surface is expressed by the elastic rebound of a weight when it falls from a certain height on that surface.

Brushes affixed to the sidewalls of the roller apparatus's outflow hopper keep the grinding cylinders clean. Adhesion of the brush to the peripheral surface of the cylinder is held by an adjustment screw fixed on the brush support rod [59].

Table 7. Effects of wheat processing on the nutritional value [59]

Processing method	Effects on nutritional value
Dry milling, decortication, degermination	The chemical composition is significantly altered by the removal of the germ and pericarp tissues. In addition to having less oil, minerals, vitamins, and even vital amino acids, refined products are essentially fiber-free. Heat treatments typically reduce the bioavailability of essential vitamins in addition to physical losses. When compared to wholegrains, the protein quality of refined goods is lower because the necessary amino acid content of germ proteins is better balanced.
Germination or sprouting	Germination or sprouting has been an effective way to improve the nutritional value of cereal-based products. The high enzymatic activity of malted cereals improves nutrient digestibility, mineral bioavailability, and the bioactivity of some nutraceuticals
Fermentation	The advantages of fermentation are comparable to those of germination. Because fermentation increases nitrogen digestibility and de novoproduces some amino acids, such tryptophan and lysine, it is known to enhance protein quality. Furthermore, the presence of antinutritional substances is reduced by these activities. Typically, fermented breads have higher and higher-quality protein content.
Cooking	Protein digestibility is somewhat decreased by water, alkali, or acid cooking because prolamins become insoluble and disulfide linkages are formed. Traditional meals like tortillas and Tô are often made by alkali-cooking maize and sorghum. Protein quality and lysine bioavailability are marginally reduced when cooking in the presence of alkali leachates, such as wood ashes, lime, or potassium hydroxide. Albumins, globulins, and prolamins are solubilized when maize is cooked in lime, which increases the amount of leftover or nonextractable proteins. Protein digestibility is somewhat decreased by these modifications. Calcium, which is extremely bioavailable, is increased when maize is cooked with lime. Limecooking is also known to increase the bioavailability of niacin. In nations where pellagra is still endemic among some populations, this is extremely pertinent or significant.
Parboiling	The nutritional content of rice and other cereals like sorghum and millets is significantly altered when they are parboiled. The endosperm is hardened and the starch is gelatinized by the heat treatment, which lessens the likelihood that the kernel would break during milling. Because the nutrients in the aleurone permeate into the inner endosperm during hydration and parboiling, parboiled rice contains increased levels of vitamins and minerals.

2.6. The culinary applications of wheat [69]

In order to manufacture a variety of meals, such as bread, crumpets, muffins, noodles, pasta, biscuits, cakes, pastries, cereal bars, sweet and savory snack foods, crackers, crisp breads, sauces, and confections (like liquorice), wheat is usually ground into flour [69].

a. Flaked, puffed and extruded wheat

All these forms are commonly used to manufacture breakfast cereals and cereal snack bars.

b. *Wheat* bran

Used to boost the amount of nutritional fiber in breads, cakes, muffins, and biscuits. Additionally, several morning cereals are made with wheat bran.

c. Wheat germ

Can be added to breads, pastries, cakes and biscuits or sprinkled onto yoghurt, breakfast cereal or fruit dishes.

d. Semolina

Primarily used to make pasta. Triticum durum is the chosen wheat strain for pasta. Halva, a Middle Eastern dish, can be made by frying it till golden brown and then adding a lot of sugar. It can also be cooked in milk to produce semolina pudding. Semolina is used in Greek baked goods.

e. Couscous

Couscous, a popular dish in North Africa, is formed from semolina grains that are mixed with a little salted water to form tiny pellets that are steamed and then dried. In Australia, instant couscous can be made by soaking it in hot water for about five minutes.

f. Burghul (also known as bulgur or cracked wheat)

Wheat is parboiled, dried, and then coarsely ground to make it. It can be used in many different recipes, including kofta, kibbeh, and tabouleh, and it can be boiled or steamed.

g. Kibbled wheat

After being cracked or split up into tiny pieces, grains are wet, steam-cooked, and then dried. Kibbled wheat can be prepared as a side dish or added to mixed grain bread.

h. Boiled wheat

In Lebanon and the Balkans, boiling wheat is used to make puddings. For usage in confections and other processed foods, wheat starch is either utilized as "corn flour" or transformed into glucose, dextrose, and other sugars.

2.6.1. Manufacturing of pasta

Around the world, pasta is becoming a more and more popular cuisine, and many formulas have been created to enhance its nutritional value. It is known that the best raw ingredient for making traditional dry pasta is semolina with a high protein and gluten content. To maximize the redesign of the manufacturing process while using alternative raw materials, it is essential to comprehend the relationship between pasta quality and processing variables.

Pasta is one of the most common and popular staple foods thanks to its sensory and nutritional value, convenience, and versatility [86]. It is reported that about 14.3 million tons of pasta are produced annually worldwide. The main producer is Italy, followed by the United States, Brazil, Turkey, and Russia. Italians are the main pasta consumers, with 23.1 kg per capita per year, followed by Tunisians (17 kg), Venezuelans (12 kg) and Greeks (11.4 kg) [86]. According to Italian law, “dried pasta” must be produced with water and durum wheat(*Triticum durum* Desf.) (semolina, coarse semolina, or wholemeal semolina) [87]. Although in the rest of the world (except for France and Greece) common wheat (*Triticum aestivum L.*) can be used for pasta production, it is well known that only durum semolina can assure thebest product quality, in terms of dough rheological properties, cooking quality and consumer acceptance [87]. However, it should be noted that common wheat is approximately 20–25% cheaper than durum wheat, making it an interesting raw material for worldwide production thanks to its high availability and (cost effectiveness/relatively low cost [87]. Pasta plays a key role in the Mediterranean Diet. WHO (the World Health Organization) and FAO described pasta as a healthy, sustainable, and quality food model. Moreover, in 2010, UNESCO (United Nations Educational, Scientific and Cultural Organization) declared pasta an intangible cultural heritage of humanity [88]. As regards processing, pasta making is a continuous process, consisting of three main steps: dosing and mixing, kneading and shaping (by extrusion or sheeting), and drying (Figure 10).

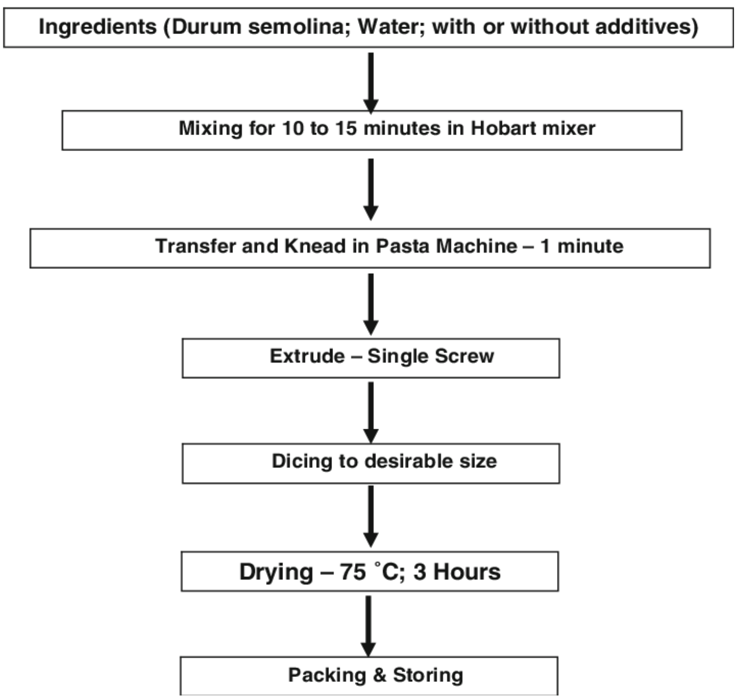

Figure 10. Process of making pasta [89]

Pasta's nutritional profile is a major factor in its popularity. Pasta's easily digestible carbs and low-fat content make it a relatively healthful food in general. Additionally, pasta can include beneficial ingredients like fiber or prebiotics [88]. Pasta appeals to a wide range of consumer demographics due to its affordable price and extended shelf life. It is commonly known that the best raw material for premium pasta is durum wheat semolina, which has a high protein content and strong gluten that can tolerate the physical stress that occurs during extrusion, drying, and cooking [89]. However, if every stage of the ongoing pasta-making process is not correctly completed, even with high-quality semolina, the production of high-quality pasta cannot be guaranteed.

Table 9 summarizes the aim of each step of the pasta making process, together with the intrinsic and extrinsic parameters affecting the dough and/or pasta. It is worth noting that the pasta-making process from gluten free raw materials is reported elsewhere [89]. So far, the effect of each step of the pasta-making process has been evaluated with respect to its impact on pasta structure and quality [89].

Table 9. Parameters affecting dough/pasta quality [89].

Operation	Aim	Intrinsic Parameters	Parameters affecting pasta
Dosing, mixingand kneading	- To dose in the right proportions both semolina and water (25–27 parts of waterparts of semolina) -To hydrate starch / proteins	Semolina particle size, protein, ash, fiber, damaged starch content Enzyme activity, residue	- Presence of a pre-mixer - Vacuum degree
Kneading and shapingby extrusion	- To (partially form gluten networks - give ashape to dough	- Gluten tenacity - Dough humidity - Dough temperature - Dough viscosity	- Mixture feeding into theextruder - Extrusion conditions
Drying	- To remove water - To assure shape integrity - Maintain nutritional quality	- Gluten tenacity - Starch pasting properties	- Air temperature - Air relative humidity - Drying time

2.5.1.1. From Dosing to Mixing

In order to create a hydrated combination with a total moisture content of roughly 30–32%, semolina and water are carefully dosed and blended together in the first phase of creating pasta. The hydration level employed in bread manufacturing (50–60% water absorption, or 45–50% moisture), which is necessary to promote the even water dispersion inside the solid mass, is distant from the amount of water given to semolina (27–29 g/100 g). In other words, while gluten is only partially generated during the pasta-making process, moisture guarantees the proper solvation of proteins [87]. The development of a continuous gluten network that can limit and avoid excessive starch swelling during cooking will only be ensured in the subsequent steps by proper protein hydration [89].

In addition to water content, other variables can influence semolina hydration and, consequently, pasta's physical characteristics and quality. These include particle size, protein, ash, fiber, and damaged starch concentration (Table 9). Low ash and damaged starch content semolina samples produce a dried product with low heat damage, low brown specks (from bran particles), and an amber yellow tint [90]. While grinding durum wheat to high particle sizes (>400 μm) ensures low-damaged starch, a medium-low extraction rate (60–65%) ensures low ash content. The decision is not so simple, though, since a medium extraction rate is related to a low milling yield (and hence productivity), while a big particle size may lead to low hydration kinetics and insufficient semolina moistening. A product with good cooking behavior must have a consistent and even protein structure, which will result in high firmness and the lack of bulkiness and stickiness [90].

In whole wheat semolina, particle size is also crucial. A positive relationship between the whole meal semolina pasta's cooking behavior (i.e., high firmness and low cooking loss) and the geometric mean diameter of the flour particles was evaluated. However, the quality of pasta cooking is adversely affected by a wide particle distribution [87]. Since the resulting pasta demonstrated more mechanical strength than pasta from the semolina/coarse bran mix, the semolina/fine bran blend is preferable when it comes to reconstituted semolina/bran blends, even though bran particle size doesn't appear to affect pasta cooking behavior [69].

2.5.1.2. From Kneading to Shaping

The main step in manufacturing pasta is shaping or forming, which tries to produce a distinct shape (Table 9). Roll-sheeting or extrusion under pressure are the two methods that can be used. In the former, the dough is kneaded into a cylinder using a screw that compresses and forces the mass in the direction of the die, where pressure can reach 10 MPa or higher. Depending on the manufacturing company, the screw's size and design can change [90].

Typically, screws are separated into three parts: the feeding part, where dough lumps are forced into the transfer part and subsequently into the extrusion part. The dough moves in a spiral motion that facilitates kneading during this flow. The bulk gains compactness at the macroscopic level, but the gluten network may experience high-intensity stretching and stresses, particularly in the last part of the extruder before the dough goes through the diet [90]. The second method of shaping the dough is to roll it through cylinder-shaped channels that progressively and gently thin it out until a sheet of the appropriate thickness is achieved [90].

Only when the dough enters the space between the two cylinders during sheeting is it put under pressure for a brief period of time; after that, it can instantly relax and recover from the deformation. At the industrial level, extrusion is the preferred method of the two methods due to its greater efficiency and diversity; in fact, it can produce more than 200 different pasta forms. Extrusion is therefore a more researched method than lamination [90]. Because the variables involved in shaping are greatly influenced by the amount of water in the dough, which must be optimized based on the physicochemical characteristics of the raw material, including particle size, content of damaged starch, and presence of fiber, the use of unconventional raw materials and/or improper dough hydration have an impact on this operation [91].

Extrusion can irrevocably destroy the protein network during cooking if the hydration stage has an impact on it, particularly when low-quality raw materials are utilized. Inappropriate extrusion settings can also result in starch swelling and gelatinization because of the heat produced by shear stress. By limiting the extrusion temperature below 50 °C and using semolina types with high starch gelatinization temperatures to postpone starch swelling and solubilization and to lessen interaction with protein reticulation, these setbacks can be minimized [91].

The pressure (measured in the last section of the extrusion cylinder) and SME are two of the extrusion variables that are helpful for assessing the process as a whole. They are related to and affected by the same factors, such as the extrusion temperature, screw speed, and degree of hydration. Studies typically take the SME parameter into account because it is well known that the pressure changes as the dough moves along the screw, reaching its highest value close to the die. The link between SME and hydration level is specifically the focus. Because it is less compact, an excessively wet dough would need a lower SME and would not provide enough resistance inside the extrusion cylinder to encourage protein aggregation and, consequently, a satisfactory gluten formation [91].

As can be seen above, a low SME lowers spaghetti's density on a macroscopic level. In the following drying phase, water that is unbound to proteins and other hydrophilic (macro)molecules would be in a free state and easier to evaporate, which would lower density. The use of NMR methods to investigate the mobility and distribution of water within spaghetti could support this theory [91]. Pressure, speed, and SME the variables of the extrusion process seem to have little or no correlation [88] with spaghetti diameter (r = 0.31–0.44) [76], indicating that other factors determine that characteristic.

As previously discussed, in addition to hydration, the formulation also influences SME. In particular, the presence of bran or oil seeds reduces SME values; in fact, the presence of lipids helps lubricate the dough on the extrusion screw. As the dough poses less resistance to extrusion, it forms spaghetti with a smaller diameter [92]. As reported by ***de la Peña et al.,*** [92], the amount of spaghetti that is released into the cooking water is inversely correlated with its diameter. Pasta quality is also impacted by the extrusion temperature in terms of cooking losses. In fact, there is a 250% increase in cooking losses when the extrusion cylinder's temperature is raised from 35 to 70 degrees Celsius [89]. Semolina proteins that denature during mixing and kneading will no longer be able to interact with one another during this step to form a protein network that can hold the starch granules in place while cooking. The final properties of pasta are positively impacted by the increase in hydration level (from 44 to 48%) and screw rotation speed (from 15 to 30 rpm) at high temperatures (about 70 °C) during extrusion [91]. In actuality, the high hydration and fast screw speed shorten the extrusion time, preventing the high temperature from damaging proteins and their capacity to aggregate [92].

It is commonly recognized that temperatures between 40 and 50 °C are ideal for the semolina pasta-making process since they do not significantly denaturize proteins or cause starch to gelatinize, but instead make it easier to extrude the dough by lowering its viscosity. These considerations were also confirmed in the study by ***Debbouz and Doetkott,*** [75].

The authors demonstrated how all the variables have a significant impact on pasta quality by using an experimental design and taking into account various levels of hydration (30%, 32%, 34%), water temperature (35–45–55 °C), mixing time (3–5–10 min), extrusion temperature (35°C, 45°C, 55 °C), and screw speed (20, 25, 30 rpm). The two factors that have the biggest effects are the extrusion cylinder's temperature and hydration level. Specifically, pasta cooking losses are minimized at extrusion temperatures of 45 to 50 °C and moisture levels of 31.5 to 32%.

The formulation and the way the experimental approach's design optimizes the process determine the ideal extrusion conditions. This is valid for different formulations. For instance, the best result (in terms of color and cooking behavior) is achieved when approximately 57 g of flour, 12 g of soy, and 31 g of water are extruded at 35 °C and 40 rpm to produce wheat spaghetti enhanced with soy flour [93]. The following are the ideal process parameters for semolina and millet pasta (50:50): Extrusion speed: 12 rpm; screw speed/feeding speed ratio = 10; extrusion temperature = 70 °C; hydration level = 30% **[93]**.

Regarding die extrusion, it is well known that the pasta's appearance is influenced by the coating substance of the die inserts: Bronze inserts create a rough surface, whereas Teflon gives the product a bright yellow, smooth appearance **[93]**. Additionally, using a bronze die has the drawbacks of consuming the part in contact with the dough more quickly, as well as lowering extrusion pressure and die extrusion speed **[92]**. Compared to Teflon-extruded items, spaghetti extruded with bronze is more porous and, as a result, more delicate (breaking strength drops by 20–30%) [93]. Additionally, compared to Teflon-extruded pasta, the rougher surface of bronze-extruded spaghetti and its higher porosity encourage the deposition of eggs by *Sitophilus oryzae* (L.) (*Coleoptera Dryophthoridae*), making it a more favorable location for insects to incubate. **[93]**.

Some research compared the effect of the type of shaping on the structure and quality of the dough. Among these, the study by ***Zardetto and Dalla Rosa***, **[94]** involved fresh pasteurized pasta (76% semolina, 19% egg, 5% water) produced by extrusion or lamination. The findings indicate that fresh pasta made by extrusion releases more dry material and absorbs more water during cooking than pasta made using lamination. Unlike lamination, extrusion does not create a uniform, continuous protein network **[94]**.

Additionally, the screw's mechanical stress causes the starch to partially degrade and most likely also creates components (reducing sugars) that can aid in the Maillard reaction. In actuality, extruded pasta had greater furosine levels than laminated raw pasta. Extruded pasta often exhibits higher consistency values than laminated pasta, however boiling lessens the distinctions between the two products, making them more comparable **[94]**. Molecularly speaking, cooking extruded pasta encourages the creation of protein bonds, a sign that the extrusion process exposes thiol groups that interact with one another during the cooking stage rather than forming a network entirely.

The low adhesiveness (assessed by instruments) and strong resilience to disintegration (assessed by sensory analysis) of cooked pasta, however, indicate that the gluten network is well-formed in laminated pasta [94]. However, the differences observed at the structural level by ***Zardetto and Dalla Rosa*** [94] do not imply sensory differences and are probably not perceived by most consumers, as they are probably masked by egg proteins.

Lastly, the study by **Carini et al.,** [95] compared different shaping processes (extrusion, rolling, and vacuum lamination) using a simpler dough system, consisting exclusivelyof semolina and water (70:30).

While the water status, or how the water interacts with the biopolymers (the ability to retain frozen water and water mobility), was only marginally affected by processing settings, the macroscopic properties of pasta (color, cooking losses, and stiffness) appeared to be process-dependent [95].

In particular, the extrusion technique appears to promote the interactions between water and biopolymers, leading to a more extensible product, because it necessitates a higher level of mechanical stress. Conversely, less strenuous lamination conditions produce a structure that is less extensible and compact but more capable of holding solids during cooking., confirming the results of ***Zardetto and Dalla Rosa***, [94].

Applying a vacuum during the lamination process appears to enhance the fresh pasta's quality indicators, producing a product that is more yellow in color and has firmness and extensibility comparable to fresh pasta made via extrusion. By better compacting the biopolymers and promoting their interactions with water, the use of a vacuum during lamination may have removed the air that was present in the dough as a result of lamination [94].

Common wheat is less able to withstand the physical forces that occur inside the press, making the distinct impact of the shaping operations on pasta quality even more noticeable. The extruded structure's increased compactness results in slower water absorption and longer cooking periods, however this does not improve the cooking behavior of dry pasta. It is evident that this characteristic is connected to the distinct arrangement of proteins. Because of the rollers' ability to better align the protein fibrils and the reduced tension, the gluten network actually looks more continuous in laminated pasta. The end product is spaghetti that is firm yet not sticky. Lastly, the optimum technique for a formulation based on semolina and enhanced with 25% buckwheat is the extrusion of a sheet whose thickness is progressively decreased by rolling [94].

Actually, this process appears to produce a structure that is both continuous (as indicated by the slower gelatinization of the starch granules) and compact (as indicated by the slower hydration kinetics), producing a product with less cooking loss, more firmness, and a decreased propensity to disintegrate during cooking [94].

2.5.1.3. Drying

The drying step, which comes last in the pasta-making process, receives special attention. As is widely known, the drying process extends the shelf life of dry pasta and provides its final physical and chemical stability qualities.

Pasta undergoes multiple simultaneous phenomena that determine its overall cooking quality (high degree of firmness, low stickiness, and minimal cooking loss). The degree of these phenomena depends on the properties of the raw materials as well as the temperature and moisture conditions used during drying.

In reality, by suggesting different combinations (and as many drying cycles), the variables that control this phase—temperature, relative humidity, and time—can be altered to encourage protein coagulation and enhance pasta's cooking behavior (Table 9). In instance, pasta cooking behavior is inversely controlled by the physicochemical changes of the primary macromolecules. When protein coagulation in the continuous network is dominant, the starch is confined inside the network, resulting in cooked pasta that is solid and bulky without any surface stickiness. In contrast, starch swells and gelatinizes before protein coagulation occurs when the protein network is weak and inelastic [96].

The effects of drying cycles at high and low temperatures on the denaturation of proteins and pasta quality [96], as well as in connection with heat damage (1980–2000) [96], were subordinated to the effects of drying on the properties of starch, including digestibility-related features. Regarding the impact of drying temperature on pasta quality, pasta manufactured with low-protein semolina can benefit from high temperature drying cycles (>65 °C) in terms of its sensory qualities [96].

Countless studies [96] have addressed the issue of starch digestion in pasta, in view of its relevance to controlling glycemia, but only a few studies have addressed the issue of protein digestion in pasta. A few of these papers have discussed problems with protein digestibility that are either related to the usage of different types of wheat or to the effects of processing. Nevertheless, it seems that none of these investigations have adequately addressed the intricacy of the raw material's protein pattern or the significance of the interactions between proteins and protein starch in these intricate matrices, either before to or following processing [96].

Furthermore, using multiple techniques and varied pasta-making circumstances has led to inconsistent results. The drying parameters (i.e., duration, temperature, and relative humidity) of published pasta research vary widely, which makes it challenging to compare results from different laboratories as pointed out by ***Murray et al.,*** [97]: because of the reinforcing effect that protein coagulation provides, drying pasta at temperatures higher than 60°C can somewhat offset the weakening of pasta's structure, which is ascribed to the enrichment and dilution of gluten.

Low heat (40 °C) was used to dry whole wheat spaghetti. exhibited superior overall look, mechanical strength, and cooked firmness compared to whole wheat spaghetti dried at a high temperature (70 °C), while having a larger cooking loss [97].

Comparing the quality of whole wheat pasta dried at 60 °C and 85 °C revealed similar results: a low temperature was useful in reducing cooking loss and boosting stiffness, even though a trained panel was unable to identify texture variations [91].

Researchers have returned to studying heat damage after discovering a link between the products of the Maillard reaction (i.e., advanced glycation end products, or AGEs) and protein digestibility [89] as well as the onset of certain diseases. AGEs include ε-pyrrole-lysine pyrraline and ε 2-formyl-5-hydroxymethyl-pyrrolaldehyde. Low levels of furosine, the most commonly used marker for determining the degree of the Maillard reaction, were found in pasta that had been dried at a low temperature.

The significance of drying conditions, particularly the use of slow and/or low-temperature drying cycles, is emphasized by many pasta manufacturers. Unfortunately, the quality of pasta and/or the degree of heat damage cannot be determined with this phrase alone.

Nearly all pasta made on an industrial scale had a furosine level of more over 300 mg/100 g protein, according to an investigation done on more than 60 pasta samples that were sold in Italy [90]. Unexpectedly, some "artisan pasta" has been found to contain these values. Furthermore, modest heat damage (furosine <250 mg/100 g) is not a guarantee of high-quality cooking, according to sensory evaluations. Even when the identical drying procedure is used, the furosine levels of pasta samples are significantly impacted by the distribution of particle sizes and, as a result, the amount of damaged starch, in addition to the protein content [90].

Sensory qualities were impacted by the higher furosine level that resulted from using wholegrain semolina rather than refined semolina. In fact, pasta that has been dried using high temperature drying cycles and has a high furosine content is thought to be more bitter than pasta that has been dried using low temperature drying cycles [42]. Conversely, with pasta prepared from whole.

According to descriptive study, drying conditions had no discernible effect on the flavor or taste of ordinary wheat. [58].

The majority of drying stage advancements have focused on cutting drying periods without sacrificing pasta quality. Recent research on the use of microwaves (either by itself or in conjunction with air drying) has been conducted in this context. In addition to cutting down on drying time, microwave drying of pasta has been shown to be highly effective since it can produce a finished product that is firmer, less gelatinized, and free of cracks than pasta dried with hot air [87].

It lengthened pasta's cooking time and enhanced its cooking resistance. Additionally, identical findings for total organic matter imply that the cooking quality of samples that were dried in different ways was similar [93]. More recently, semolina pasta has been evaluated at the lab scale to determine the impact of vacuum drying a process that removes moisture from food goods under low pressure on pasta quality [91]. Vacuum drying has a higher drying rate (i.e., water evaporation happens more easily) and a lower drying temperature than traditional drying. Improved moisture transmission could prevent the development of surface barriers, which would otherwise result in internal product stress [87].

Thus, using vacuum-drying may improve cooking quality (i.e., high water absorption and hardness, low cooking loss and adhesiveness) by lowering internal stress and preventing structural damage [85]. Additionally, oxidative degradations, such as browning or fat oxidation, are reduced when moisture is eliminated in the absence of oxygen, giving the pasta a vivid yellow hue [95].

At the industrial level, there are innovative drying lines that can significantly reduce the size of the plant while drying pasta in less than two hours for small pasta and approximately three hours for long pasta [97]. The company that makes the drying equipment claims that the produce from these systems is of higher quality, but no evidence has been shared with the scientific community to support this assertion. In truth, the majority of processing studies are carried out by pasta producers and/or pasta factories, and as such, they are governed by privacy-related firm standards [97].

2.6.2. Making the cookie

The Latin term "panis biscoctus," which refers to the twice-cooked bread typically prepared for sailors and known as "ship biscuits," is where the word "biscuit" originates [98] "Hard dry bread, made to carry to sea" is the primary definition of a biscuit provided by Dr. Samuel Johnson. Britain claims that "biscuit" refers to foods like wafers, cookies, and crackers. The biscuit was first created by the British [98].

Today, the craft-based, labor-intensive biscuit sector has evolved into a well-mechanized, science-based one. These days, biscuits are used as luxury presents, snacks, baby food, dietary supplements, dog and cat food, and adorned objects with chocolate, cream, almonds, and other flavors [98].

Because of this, there is a great deal of room to improve the biscuit's nutritional value in order to satisfy the enormous customer demand for biscuits made with healthier components and to make them more palatable and nutritious [98].

Wheat flour (60%) bran (7%), potassium bitartrate, glucose syrup, and salt were the ingredients for the whole grain biscuits. Depending on the amount specified in the recipe derived from the experimental design (Table 10) supplemental material, eggs, margarine, and dextrose were added [98]. To get the proper pH level, sodium bicarbonate was added. Depending on the needs of the technology, the water content varied from 1.6% to 5%. According to the values in the model produced by the recipe design, milk and dextrose were also added.

Table 10. Processing conditions assumed during wholegrain biscuit industry [98]

Treatment	Minimum	Optimum	Maximum
DON bran level (µg/kg)	600	1050	1500
Dextrose (%)	15	19	23
Milk (%)	-	-	-
Eggs (%)	4	6	7
Margarine (%)	10	15	20

Creaming, preparing the dough, and baking were the main processes in the process of making whole grain and cocoa biscuits. Initially, a test planetary kneader XBE10 (Dito Sama Electrolux, Stockholm, Sweden) was used to combine all solid powder materials with wheat flour for two minutes. Another test planetary kneader, the BE5 (Dito Sama Electrolux, Stockholm, Sweden), was used to combine the dextrose and margarine separately for three minutes (creaming step). Later, powders and cream were combined for three minutes. After shaping the resultant dough, circular pieces weighing roughly 10 g and measuring 4 cm in diameter were formed. The dough was then allowed to rest at room temperature for 10 minutes. A pilot-scale dynamic oven (Tagliavini, Parma, Italy) was used for baking. The procedure of producing biscuits is summarized in Figure 14.

Measuring all ingredients on 100g flour basis

↓

Creaming (Mixing of sugar powder and fat)

+

Mixing of all ingredients (for 10min)

↓

Blending

↓

Addition of water

↓

Dough Preparation

↓

Kneading

↓

Resting for 10 minutes

↓

Sheeting (By rolling balls of dough on wooden platform)

↓

Cutting to desired thickness by using hand operated metal dye cutter (about 10g biscuit)

↓

Placing into greased trays

↓

Baking (25 min at 160^{o}C)

↓

Cooling for 10 min at Room temperature

↓

Packaging in HDPE bag

↓

Storage in dry condition

Figure 14. The flowchart for preparation of biscuits [98].

2.7. Methods for assessing the quality of wheat

Wheat is the most important crop in the EU in terms of both acreage and output, with a global production of 730.5 million tonnes in 2015, ranking third in cereal production after rice and maize [99]. About 65% of the wheat produced is used for human sustenance, in addition to the fact that it is not used for industry, energy, or fodder. Large-scale wheat cultivation is justified by the crop's ability to adapt to a variety of environmental conditions, its high yield potential and long-term storage capacity, and, lastly, its many uses as bread, pasta, noodles, cookies, and other food products, which make it the world's main source of protein and carbohydrates [99].

Test weight, heat damage, foreign material, overall flaws, shrunken and broken kernels, wheat of other classes, contrasting classes, and sample grade standards are the variables that determine grade. Additional "optional" tests, including protein, falling number, single kernel hardness, mycotoxin, and pesticide residue analysis, are available for official testing [99].

a. Test weight per bushel

The weight of grain needed to fill a level Winchester bushel with a capacity of 2.150 cubic inches (35.24 liters) is known as the test weight per bushel. An authorized device with a kettle capacity of one dry quart (1.101 liter) is used to calculate the factor ″test weight per bushel″. A Boerner Divider is used to cut 1,350 grams of wheat from the representative sample in order to make this determination [100].

The work sample is put into the closed hopper that is positioned in the middle of the kettle in order to calculate the test weight. To let the grain fill the kettle, the valve is rapidly opened. The extra grain is removed from the kettle's top using three full length zigzag strokes with a conventional stroker held in both hands with the flat sides upright. The kettle is placed on the scale platform with care. An electronic scale measures the weight and converts it to pounds per bushel or kilograms per hectoliter [100].

One grading factor is the test weight per bushel. Normally, it is stated in pounds per Winchester bushel, but it can be changed to kilograms per hectoliter upon request [100].

b. Shrunken and Broken Kernels

For wheat, broken and shrunken kernels are a grading criteria. The inspector places 250 grams of wheat on a 0.064 × 3/8 inch (1.626 mm × 9.545 mm) oblong-hole sieve and mechanically shakes the sieve 30 times from side to side in order to identify shrunken and broken kernels [99]. The Strand Sizer, the device that sieves the sample, has a stroke counter and starts and stops in the same spot every time. It takes about 1s to perform one stroke [100].

c. Damaged Kernels

Heat damage and total damage are the two types of damaged kernels that determine a grade. Although they are included in the total damage, heat-damaged kernels are reported separately from all other types of kernel damage **[99]**.

To ascertain whether any kernels have been significantly discolored or harmed by physical or biological factors, the inspector visually inspects 50 grams of the wheat sample for heat damage and 15 grams for other damage types **[100]**.

2.7.1. Appreciation of soft wheat

Soft wheat (*Triticuna aestiuum*) is primarily used for animal feed and bread production in the broadest sense. Thus, the two parts of wheat grain's usage value will be covered **[101]**:

- The value in bread making or baking value.
- Nutritional value or fodder value.

The existence of two categories of vital components—proteins and starch—determines the wheat grain's usage value. Let's look at the components that are essential to the processes involved in manufacturing bread, like fermentation, dough swelling, and cooking, or that determine the grain's nutritional worth.

2.7.1.1. Baking value

The baking value represents the ability of wheat or flour to produce beautiful and good bread. These abilities depend on two groups of factors **[102]**:

a. The strength of the wheat

The dough's plastic qualities, which are strongly correlated with the amount and caliber of gluten, as well as the dough's fermentative activity, define its strength: The flour's sugar content and the enzymatic balance, which must accompany the transformation, are the two factors that determine its fermentative activity: maltose, starch dextrins (glucides produced by heating the starch to 160°C or by hydrolyzing it with acid at about 100°C).

2.7.1.2. Strength assessment

- Extraction and dosage of gluten
- Identification of nitrogenous materials
- Swelling properties of proteins in an acidic environment = Zeleny sedimentation test.

The types of wheat and the pedoclimatic circumstances that preceded the plant's growth and harvest are the main factors that determine the baking value. It can be evaluated by multiple techniques. The bread-making test is the most comprehensive. Additionally, we employ indirect techniques to describe the doughs' plastic characteristics (gluten index, Chopin alveogram) or fermentation quality (Hagberg falling index). These tests will be used to evaluate the flours' strength or the doughs' fermentative activity **[100, 101]**.

a. Falling Number

The falling number test's measurement of enzyme activity has an impact on the quality of the final product. For instance, yeast in bread dough needs carbohydrates to grow correctly, so the dough must have some degree of enzyme activity. However, excessive enzyme activity indicates an excess of sugar and a deficiency of starch. Too much activity causes sticky dough during processing and a bad texture in the final product since starch gives bread its supporting structure. Enzymes can be added to the flour in a variety of ways to make up for a dropping number that is too high. Enzymes cannot be eliminated from the flour or wheat if the decreasing number is too low, which is a major issue that renders the flour useless [101].

Method [100, 101]

1. In a glass falling number tube, a 7 g sample of milled wheat or flour is weighed, mixed with 25 milliliters of distilled water, and shaken to create a slurry. To ensure a representative sample, a minimum of 300 grams of wheat should be ground before doing a falling number test.

2. As the slurry is heated in a boiling water bath at 100 degrees Celsius and stirred constantly, the starch gelatinizes and forms a thick paste.

3. The time it takes the stirrer to drop through the paste is recorded as the falling number

b. Farinograph

One of the most often used methods for evaluating the quality of flour worldwide is the farinograph test. The results are used as formulation parameters to determine how much water is needed to make a dough, assess how components affect mixing qualities, determine how much flour is needed for blending, and verify flour consistency.

The findings are also used to forecast the impacts of processing, such as the amount of mixing needed to produce the dough, the dough's tolerance to excessive mixing, and its uniformity throughout manufacturing. Results from farinographs can also be used to forecast the textural features of final products. For instance, robust product texture is associated with strong dough mixing characteristics [101].

By measuring the dough's resistance to the paddles' mixing action, the farinograph ascertains the dough and gluten characteristics of a flour sample.

Farinograph results include absorption, arrival time, stability time, peak time, departure time, and mixing tolerance index [100].

Method

1. A flour sample of 50 or 300 grams on a 14 % moisture basis is weighed and placed into the corresponding farinograph mixing bowl.

2. Water from a buret is added to the flour and mixed to form a dough.

3. As the dough is mixed, the farinograph records a curve on graph paper.

4. The amount of water added (absorption) affects the position of the curve on the graph paper. Less water increases dough consistency and moves the curve upward.

5. The curve is centered on the 500 Brabender unit (BU) line ±20 BU by adding the appropriate amount of water and is run until the curve leaves the 500 BU line.

c. Alveograph

In order to guarantee a more consistent procedure and final product, flour millers and processors use the alveograph test findings, which establish common requirements. When assessing the dough properties of weak gluten wheats, the alveograph works effectively. For cakes and other confections, weak gluten flour with a long L value (extensibility) and a low P value (gluten strength) is preferable (Figure 16). For breads, strong gluten flour is preferred since it has high P values [101]. By measuring the power needed to blow and shatter a dough bubble, the alveograph calculates the gluten strength of a dough. P, L, and W values are among the outcomes. A stronger dough has a higher P value, meaning it takes more force to blow and break the bubble.

The dough can stretch to a very thin membrane before breaking if the bubble is larger. The dough's extensibility, or its capacity to extend before breaking, is indicated by a larger bubble (L value). A larger bubble will have a larger area under the curve (W value) and require more force. [100, 101]. The alveograph test measures and records the force required to blow and break a bubble of dough.

- P Value is the force required to blow the bubble of dough. It is indicated by the maximum heightof the curve and is expressed in millimeters (mm).
- L Value is the extensibility of the dough before the bubble breaks. It is indicated by the lengthof the curve and is expressed in millimeters (mm).
- P/L Ratio is the balance between dough strength and extensibility.
- W Value is the area under the curve. It is a combination of dough strength (P value) andextensibility (L value) and is expressed in joules.

Method

1. A sample of 250 grams of flour is mixed with a salt solution to form a dough.

2. Five 4.5 centimeter circular dough patties are formed and then rested in the alveograph in a temperature-regulated compartment at 25 °C for approximately 20 minutes.

3. Each dough patty is tested individually. The alveograph blows air into a dough patty, which expands into a bubble that eventually breaks.

d. Glutomatic

The wet gluten test determines the amount and quality of gluten present in wheat or flour samples. The properties of flour dough's elasticity and extensibility are due to gluten. Wet gluten is a standard flour specification used by end users in the food sector and indicates protein concentration [101]. By removing the starch and other solubles from the flour or ground wheat sample using a salt solution, the wet gluten level can be ascertained. Wet gluten is the residue left over after washing. The gluten is pushed through a sieve during centrifugation. The percentage of gluten that stays on the sieve is known as the Gluten Index, and it serves as a gauge of gluten strength. Strong gluten is indicated by a high gluten index. Results for wet gluten content are given as a percentage based on 14% moisture; for instance, 35% for strong gluten, high protein wheat, or 23% for weak gluten, low protein wheat [101].

Method

1. A 10 g sample of flour or ground wheat is weighed and placed into the glutomatic washing chamber on top of the polyester screen.

2. The sample is mixed and washed with a 2 percent salt solution for 5 minutes.

3. The wet gluten is removed from the washing chamber, placed in the centrifuge holder, and centrifuged.

4. The residue retained on top of the screen and through the screen is weighed.

e. Amylograph

The amylograph test quantifies the enzyme activity and flour starch characteristics that arise from sprout damage (alpha amylase enzyme activity). High enzyme activity in wheat indicates sprouting, which results in sticky dough that can cause issues during processing and generate weak-textured, poorly colored products. Medium to high peak viscosity flour is recommended for Asian noodle products because it improves the texture of the noodles [101].

The rapid Visco analyzer (RVA) and the amylograph are both used to measure the viscosity characteristics of starch. Around the world, the amylograph is more widely utilized. Compared to the amylograph, the RVA requires a smaller sample and requires less time [101]. By measuring a flour and water slurry's resistance to the stirring action of pins or paddles, the amylograph determines viscosity. The starch granules in the slurry swell and turn into a paste when heated. A thicker slurry has a higher peak viscosity and more resistance to the pins during stirring.

In general, a thicker slurry produces better products and shows less enzyme activity. Results from an amylograph show peak viscosity [101].

Method

1. A sample of 65 grams of flour is combined with 450 milliliters of distilled water and mixed to make a slurry.

2. The slurry is stirred while being heated in the amylograph, beginning at 30°C and increasing at a constant rate of 1.5°C per minute until the slurry reaches 95°C.

3. The amylograph records the resistance to stirring as a viscosity curve on graph paper.

f. Sedimentation

The amount and quality of protein in samples of ground wheat and flour are determined using the sedimentation test. Sedimentation volume was positively correlated with either loaf volume or gluten strength. Both milling operations and wheat breeding use the sedimentation test as a screening technique. The pulverized wheat or flour sample is kept in an acidic solution to perform the sedimentation test [100]. Gluten proteins in milled wheat or flour expand and precipitate as a sediment during the sedimentation test. For low-protein wheat with weak gluten, sedimentation values can be as low as 20 or less, while for high-protein wheat with strong gluten, they can reach 70 or higher [100].

Method

1. 3.2 g of flour or ground wheatis weighed and placed in 100 ml glass stoppered graduated cylinder. 50 ml of water is added to the cylinder and mixed for 5 minutes.

3. Lactic acid solution is added to the cylinder and mixed for 5 minutes.

4. The cylinder is removed from the mixer and kept in upright position for 5 minutes.

5. The sedimentation volume is recorded.

2.7.1.3. Bread making test

By examining the properties of the dough, the crumb, the bread, and the bread's volume, the bread-making test enables us to determine whether flour is suitable for producing bread [102].

Table 11. Additional ingredients expressed as a percentage of flour weight [102]

Flour*	100 grams
Dry yeast	1 gram
Sugar	6.0 grams
Salt	1.5 grams
Shortening	3.0 grams
Water	Variable (58–70 g)
Malted barley	0.2 grams

*14% moisture

Procedure [102]

1. Flour and other ingredients are mixed with a yeast suspension to form a dough.

2. The dough is mixed until it reaches optimum dough development.

3. The dough is rounded and placed into a fermentation cabinet at 30°C and 85% relative humidity for 105 minutes.

4. First Punch – The dough is passed through a sheeter, folded twice, and returned to the fermentation cabinet for 50 minutes.

5. Second Punch. The dough is passed through a sheeter, folded twice, and returned to the fermentation cabinet for 25 minutes.

6. The dough is molded into a cylinder shape and proofed in a pan for 62 minutes.

7. The dough is baked in a 215 degrees' Celsius oven for 24 minutes and then cooled to room temperature.

The pan bread test gives consumers information about the qualities of flour. Bakers require flours with reliable performance, particularly in high-volume commercial settings. A consistent product that satisfies volume, color, and texture requirements is what customers want.

2.7.2. Appreciation of *durum* wheat

2.6.2.1. Semolina value

A batch of durum wheat's semolina value indicates both the potential for semolina yield and the quality of its end products. The behavior of durum wheat during milling is determined by a multitude of parameters [102]. Gaining insight into the underlying mechanics can help control and optimize it. The creation of techniques for assessing grain properties in order to ascertain their semolina value continues to be a significant problem for primary processing companies, in addition to the identification of key elements [103]. We can determine whether durum wheat is suitable for being turned into semolina by using a few selection criteria:

a. The mitading rate [103]

There are more or less large patches of floury starch in the horny base of the albumen due to the mitadine grains. Mitadinage results in whitish pits in the semolina and the pasta that is produced, as well as a decrease in semolina output. This accident is prevented by late nitrogen fertilization before to heading. Algeria's climate makes it impossible to apply this nitrogen fertilizer at this late stage, which also makes wheat more susceptible to plant diseases like fusarium wilt and oidi. Because of this, adopting mitadinage-resistant cultivars and using appropriate fertilization is a safer and more cost-effective alternative, especially for our nation.

b. Thousand kernel weight (TKW) [103]

The mass of the wheat kernel is measured using the thousand kernel weight (TKW) method. To better characterize the composition of wheat kernels and possible flour extraction, wheat breeders and flour millers employ it in addition to test weight. One can anticipate that wheat with a higher TKW will have more potential for flour extraction. The weight of one thousand wheat kernels in grams is known as the thousand kernel weight. Kernel mass is estimated using this technique. The Single Kernel Characterization System can also be used to determine this measurement.

Method

1. Prepare a 500 g sample of wheat by removing all dockage, shrunken and broken kernels, and other foreign material.
2. Divide the sample several times using a mechanical divider until you have approximately 50 grams.
3. Count 1,000 kernels using a mechanical counter and weigh.

c. Protein content

For wheat, it typically ranges from 7 to 18 percent (7 to 18 percent for durum wheat; 3 to 16% for soft wheat). Agroclimatic and genetic factors have an impact on it [104].

Therefore, wheat growers, millers, and bakers are interested in developing a dependable and simple-to-measure indicator for estimating baking quality, ideally early in the production chain, ideally at the whole grain stage [104].

Since the protein level satisfies these time and effort requirements, it is regarded as the most significant factor influencing bread volume, or baking quality, and the most pertinent attribute that affects price at corn exchanges. Because protein content can be quickly and accurately estimated using near infrared spectroscopy (NIRS), it is generally used as a measure of baking quality [104].

However, relying solely on protein content as a measure of baking quality has a number of disadvantages. First, with R_2 values ranging from 0.01 to 0.86, the degree of association between bread volume and protein content seems to vary greatly depending on a number of factors (such as local site circumstances, weather, fertilization amount, and wheat type). Second, as preliminary research has indicated, the correlation between bread volume and protein content may not necessarily be linear [104]. Although high protein levels are more likely to cause a saturation effect, these factors have gotten relatively little attention. Only linear connections were evaluated in the majority of research [104].

Thirdly, as the protein content increases, different types of bread from the same quality class may show varying increases in bread volume (i.e. the regression varieties have different slopes. As a result, some types with low protein content that yield good baking quality are undervalued when measured solely by protein level. As a result, these types are not widely accepted by farmers [104].

Fourth, farmers optimize their agronomic practices for grain protein content and production for financial reasons. Farmers may increase N fertilization and/or divide it into three or four applications as a way to boost grain protein content. Therefore, the late nitrogen treatment specifically tries to boost protein content, but it may also affect the environment because weather circumstances have a considerable impact on the efficiency of such a late nitrogen application in addition to the predicted yield [104].

Anette et al., [104] noted that with a weather-dependent N absorption efficiency ranging from 15 to 75%, increasing the protein content from 12 to 13% necessitates twice as much N at late application. Overly dry soil prevents nitrogen from being taken by plants and instead stays in the soil, which can lead to gaseous N emissions into the atmosphere or nitrate seeping into groundwater. Thus, when considering all of the points put forward, it is necessary to reevaluate the usage of protein content as the sole metric for evaluating the quality of baked goods and to find quick and trustworthy substitutes.

A number of indirect approaches, such as the SDS sedimentation test, lab-on-chip capillary electrophoresis, glucose peak test, spectrophotometric and fluorimetric techniques, and microbaking test, were taken into consideration as substitutes for estimating the baking quality of wheat [104].

None of these techniques can compete with NIRS in terms of sample preparation convenience, staff training, measurement speed, and accuracy, even though they provide useful information on the interaction of factors influencing bread quality. As a nondestructive method, NIRS uses minimal amounts of material to process many samples in a given time unit. A single evaluation of a given sample can be used to predict a large number of parameters.

As a result, the wheat production chain has numerous applications that are monitored in either the transmission or diffuse reflectance modes, including breeding, production, trading, storage, and processing. It is generally known that wheat grain and flour qualities including protein and moisture, wet and dry gluten, gliadine and glutenine content, and ash content can be controlled using near infrared spectroscopy (NIRS) [104].

d. Speckle

The development of the mycelium of various mushrooms results in pitted semolina from the speckled grains, which gives the pasta its black pits [102, 103,105].

2.6.2.2. Dough value

Visual inspections, chemical analysis, rheological tests, physical tests, and manufacturing tests are the procedures used to quantify the ability of semolina to be converted into pasta [103, 104]. This is the process by which semolina can be turned into pasta. It combines two key elements:

a. Visual quality [103]

Look for pastes that are golden yellow in color and do not show pitting. Fungi (Fusarium, Alternaria) are responsible for the brown to blackish spots on the husks of the speckled grains, which are located at the furrow and/or germ. The latter primarily grow on ears that have been attacked by specific parasites or shed (Thrips). As a result, these colored regions are partially visible as black spots in the semolina and subsequently in the pasta following grinding, which lowers the products' market value.

b. Culinary quality [103]

It covers a variety of topics, such as the texture (firmness, elasticity, and surface condition) of the cooked goods and the hold of the dough both before and after cooking.

Culinary quality is greatly influenced by the plastic properties of the wheat used, but it is also influenced by the industrial process (kneading and drying into pasta).

2.7.3. Couscous Value

A semi-prepared dish that has been made since ancient times as part of winter preparations is couscous. Durum semolina and water are the ingredients used to make industrial couscous, a type of pasta [105].

Nowadays, couscous is produced mechanically utilizing extrusion technology in several nations, including Turkey. Each granule of couscous is an agglomeration of many semolina particles. Nonetheless, Turkish women can traditionally make it by hand. The components and production processes of the commercial couscous differ greatly from those of the traditional varieties produced in the Middle East and several African nations. In addition to having numerous names in other nations, it has gained popularity in Spain, Portugal, Italy, and Greece [105]. WF dough is used to cover wheat bulgur granules, providing them a spherical shape, to make traditional couscous.

For couscous preparation, wheat bulgur (8.4 g), different flour blends (total 30.0 g; 70% WF, 20% legume flour and 10% wheat germ) were used [105]. A big bowl was filled with wheat bulgur. Then, when the flour blend was added, the mixture was rolled by hand. Thus, the dough covered and coated the bulgur granules' surfaces [105].

These rolling and wetting procedures were repeated until the couscous particles had grown to a diameter of three to five millimeters. To reduce the moisture level below 10%, the couscous was then dried on a flat plate for three to four days at room temperature (25±1°C). Samples of dried couscous were then stored at room temperature in sealed glass containers until they were needed. The most significant aspect of couscous qualities in terms of customer acceptance is its cooking ability [105].

In general, a high protein content (13.5% on a wet basis) and good preservation by an acidity level that complies with international criteria define a semolina's couscous value (Table 12).

Table 12. Nutritional composition of durum wheat semolina (100 g) [105]

	Durum wheat semolina (100 g)
Proteins	12.68
Fats (lipids)	10.50
Carbohydrates	72.83
Fibers	03.90

Compared to pasta, the semolina kinds used to make couscous have bigger particle sizes. One-third large semolina (630–800 micrometers) and two-thirds fine semolina (250–630 micrometers) are combined to make industrial couscous) [105].

Rolling and steaming (at 180°C for 8 minutes) are the next steps in the manufacturing process, which starts with the semolina and salt being continuously hydrated (around 30 liters of water for 100 kg of semolina). While the wet couscous goes through the drying and drying stages during the cooking stage, the hydration and rolling stages are essential because they cause a noticeable oxidation of the carotenoid colors through the activity of delipases and lipoxygenases. cooling. The drying process is divided into two phases: the first lasts 120 minutes at 65°C, and the second lasts 270 minutes at 55°C [105].

The final product's organoleptic properties are significantly influenced by drying. A planchister is used to separate or sift the cooled and dry couscous. After that, it is moved to storage silos and hygienically packaged in cardboard boxes in compact forms. Industrial couscous is a stable product with uneven surfaces and varied forms (Fig 15).

Couscous's cooking qualities are often evaluated by its surface condition, which should be non-sticky, and its disintegration, which shows how the couscous particles have broken down. An industrial couscous line's current flow rate guarantees a consistent output of 500–1500 kg/hour [105].

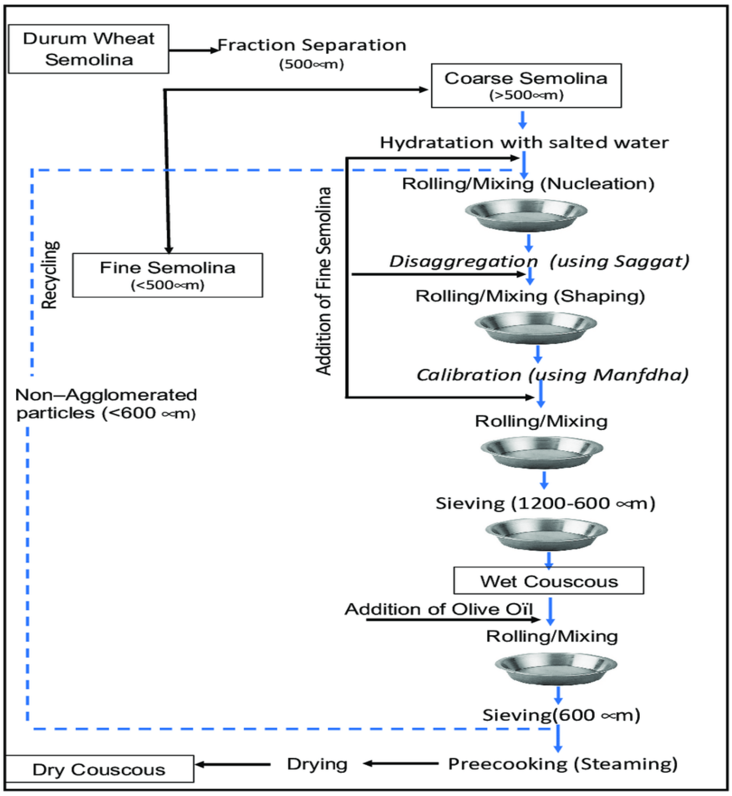

Figure 15. Diagram of traditional couscous making identified from the handmade process [105]

Acorn couscous has higher levels of dietary fiber (3.13% DM), ash (1.54% DM), and fat (4.46% DM) than wheat-based couscous, according to biochemical analysis. difficult (0.51%, 0.91%, and 3.32%, in that order). However, compared to couscous made from acorns (13.54% DM), couscous made from durum wheat has a higher protein content (14.96% DM) [105].

3. Effects of deterioration on the quality of wheat seeds

For wheat seeds to be stored safely, moisture-induced mildewing and deterioration are major issues that need to be addressed. Grain deterioration and mildewing during storage are caused by a number of mechanisms, according to earlier research. First of all, temperature increases during grain storage are common and can be brought on by both solar radiation and the respiration of grain cells [106].

Grain seeds may lose nutrients and weight as a result of the high temperature, which can also foster an environment that is conducive to grain cell respiration. Second, insect activity can expedite the deterioration process during storage and harm grain seed structure [106]. The quantity of insects in large-scale grain storage facilities cannot be completely eliminated, even though fumigation can decrease their activities or densities. As a result, the damage brought on by insect activity also affects grain storage. Thirdly, prior research has shown that wheat seeds deteriorate quickly in high humidity storage settings [107].

One of the primary processes is that fungi can develop quickly in a humid environment, damaging wheat seed surfaces and consuming nutrients.

When storing wheat seeds, moisture is a major concern. On the one hand, wheat seeds' culinary qualities depend on their moisture level. However, moisture can alter the storage conditions and further affect wheat seed characteristics.

Reed et al. [108] revealed that moisture can hasten wheat seed respiration and encourage spoiling when they being stored.

The beneficial effects of moisture on the respiration and spoiling of numerous other grain kinds were also documented in earlier research [106]. However, little research has been done on how moisture gradients in wheat seeds affect the temperature variations of grain mass. Additionally, earlier research ignored the connection between moisture and fungal development in favor of concentrating only on cell respiration [107].

To the best of our knowledge, moisture transfer always takes place in the grain bulk during storage, which causes a percentage of the wheat seeds' moisture content to dramatically increase. Additionally, microbial activity in grain bulk, especially fungal activity, may harm wheat seeds' exterior structure and result in spoiling. [109].

Some fungal species also create toxic mycotoxins. Aspergillus and Penicillium are two of the xerophilic species, which are the most dangerous toxigenic species. Tolerable levels of mycotoxins are strictly regulated globally because mycotoxin contamination of cereal grain is a global public health problem and a persistent issue for the cereal-food industries, who face the difficulty of continuously checking mycotoxin content in their primary materials. Grain moisture levels, which support biological activity in the grain environment, have a direct impact on the proliferation of mycotoxin-producing species. As a result, early detection of grain and mold respiration can predict the growth of mold in stored grain bulks. A preventive approach can be used to manage the risk of mycotoxigenic fungus causing stored grain to deteriorate [109].

The five pillars of integrated control of mold spoiling concerns in stored grain are as follows: i) Preventing the growth of mold by maintaining grain moisture below the critical limit of fungal growth; ii) Accurately monitoring temperature changes and grain aw during storage, linked to the monitoring of early indicators of storage fungal respiration activity; iii) Reducing trends in grain bulk moistening through physical intervention; iv/Restricting the spread of mycotoxin contamination to processed cereal products by using physical treatments (ozone, grain peeling, or abrasion); v/Using bio-competitive bacterial or fungal strains to stop the growth of mycotoxigenic fungus in grain bulks [108].

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