NTRODUCTION

A cereal is a plant cultivated primarily for its grains, known as caryopses. The term “cereal” comes from the Latin *cerealis*, referring to Ceres, the Roman goddess of harvest. These plants belong to the Poaceae family (formerly known as Gramineae) and include wheat, rice, maize, barley, and oats.

Globally, cereals play a crucial role in agriculture: about 720 million hectares are devoted to their cultivation, representing 51% of arable land, 14.6% of the world’s agricultural area, and 5.5% of the Earth’s land surface.

Maize is the most widely produced cereal in the world, with an estimated production of 817 million tons in 2009 (FAOSTAT). It is a staple food in many countries and is also widely used for animal feed and various industrial applications. Its high genetic variability allows it to grow in a wide range of climates, from tropical to temperate regions.

Wheat is another major cereal, cultivated under diverse climatic conditions. It has been a staple food for many civilizations in Europe, Asia, and North Africa for about 8,000 years. In 2007, global wheat production exceeded 600 million tons, ranking it third after maize and rice. Wheat is used in a wide variety of food products, as well as in animal feed, starch production, and ethanol.

Rice is a staple food for more than half of the world’s population. With a production of 685 million tons in 2008, it ranks second after maize. The largest producers are China, India, Indonesia, and Pakistan. Rice cultivation generally requires more water and labor than other cereals.

Uses of Cereals

In human nutrition, the most commonly consumed cereals are wheat, rice, and, to a lesser extent, maize. They are consumed in various forms:

- **Whole grains**: rice, maize, wheat (often precooked, such as bulgur)
- **Flour**: soft wheat, rye, spelt (used in baking and pastry making)
- **Semolina (precooked flour)**: durum wheat (couscous, pasta), maize (polenta), fonio
- **Flakes**: oats, maize, rice
- **Pasta products**: durum wheat, rye, spelt, rice

I- Cereal Grains

I-1 Histological Structure of the Wheat Grain

“Wheat” is a generic term that refers to several cereals belonging to the genus *Triticum*. From an economic point of view, the two most important types are:

- **Durum wheat** (*Triticum turgidum* subsp. *durum*)
- **Soft wheat** or common wheat (*Triticum aestivum*)

Durum wheat differs from soft wheat by its **vitreous endosperm** and its **higher protein content**. The essential difference between the two species lies in their genome:

- Durum wheat is **tetraploid**
- Soft wheat is **hexaploid**

The wheat grain is a **caryopsis**. It has an ovoid shape and presents a groove (crease) on the ventral side that extends along its entire length. At the dorsal base of the grain is the **germ**, topped by a brush.

The wheat grain is composed of three main parts (Figure 01):

- The **pericarp (bran)**: about 13%
- The **endosperm**: about 84%
- The **germ (embryo)**: about 3%

I-1-1 Bran (Outer Layers of Wheat)

The bran is a **cellulosic outer layer** whose role is to:

- Protect the seed during its development in the ear
- Limit the entry of molds and bacteria
- Allow the passage of air and water

In semolina milling, it gives rise to **bran (son)**.

The thickness of the bran varies, and it is composed of three groups of fused layers:

1. Pericarp (Fruit Coat)

Composed of three cellular layers:

- **Epicarp**: protected by a cuticle and hairs
- **Mesocarp**: made of transverse cells
- **Endocarp**: composed of tubular cells

2. Seed Coat

- Made up of two layers of cells

3. Nucellar Epidermis

- Located directly on the underlying endosperm

I-1-2 Endosperm

The **endosperm** occupies almost the entire interior of the grain. It is mainly composed of tiny **starch granules**, surrounded by protein filaments whose thickness is on the order of a micrometer (µm).

Two types of starch granules can be distinguished:

- **Large granules (A-type starch):** 20–40 µm
- **Small granules (B-type starch):** less than 10 µm

The endosperm contains most of the **energy reserves** that nourish the seedling during germination. It also includes the **aleurone layer**, which surrounds the starchy endosperm.

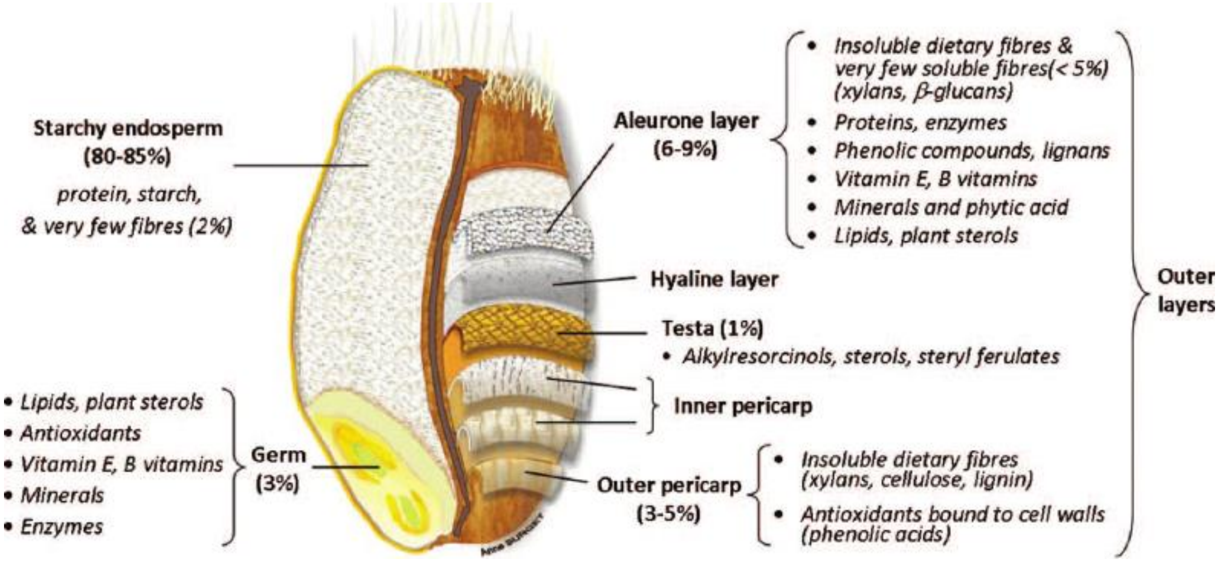

Figure 01: Histological Structure of the Wheat Grain

I-1-3 Germ

The germ is the embryo that will develop into a future plant. It consists of two parts:

- The embryonic axis, composed of meristematic parenchymal cells with thin, non-lignified walls
- The scutellum (cotyledon), which functions as a storage organ

In current milling processes using roller systems, the germ is generally removed from semolina and ends up in the by-products (bran and remilled products).

I-2 Biochemical Composition of Wheat

The wheat grain is mainly composed of:

- Starch (about 70%)
- Proteins (10–15%)

Other minor components (only a few percent) include:

Lipids ,Cellulose , Free sugars , Minerals ,Vitamins

The quality of wheat is influenced by each of these components, either individually or through their interactions.

I-2-1 Proteins

Durum wheat contains about 12% protein :

Gliadins and glutenins represent 80–95% of the insoluble proteins in wheat and together form gluten. The remaining proteins are soluble proteins, such as albumins and globulins.

These proteins are responsible for the quality of pasta products.

quantitatively, protein content mainly depends on agronomic conditions during plant growth.

And qualitatively, it depends on protein properties:

- Insoluble proteins (gliadins and glutenins) combine in the presence of water to form gluten.
- This protein network gives the product viscous and elastic properties.

I-2-2 Carbohydrates

Carbohydrates are mainly represented by starch, which accounts for about 60–70% of the grain, Other carbohydrates include pentoses and cellulosic materials.

I-2-3 Lipids

Wheat grains are low in lipids, with a content of 2.7%. Lipids are minor components of wheat**:**

- Some are free, but most are associated with major components such as starch and proteins.
- Despite their low quantity, they play an important role in technological processes**.**

Lipids act as:

- Lubricants and emulsifiers
- Contributors to the formation of volatile compounds in dough, in interaction with gluten and starch

They therefore influence the quality of the final product.

However, during storage, lipids may undergo oxidation, especially due to their polyunsaturated fatty acids, which are easily oxidized and can lead to product deterioration.

I-2-4 Minerals and Vitamins

Wheat shows significant variation in mineral content, including: Potassium: 340 mg/100 g , Phosphorus: 400 mg/100 g ,Calcium: 45 mg/100 g , Sodium: 8 mg/100 g

Wheat grains are also rich in vitamins, particularly those of the B group:B1, B2, B3, B6, and B9

I-2-5 Water

The water content of wheat varies depending on the variety and harvest conditions, averaging 13.5%. This moisture level has two important effects:

- It allows long-term storage
- It helps inhibit the growth of microorganisms, especially molds

I-3 Properties of Wheat Proteins

I-3-1 Definition

Gluten is a group of proteins found in many cereal grains such as wheat, rye, and barley.

These proteins:

- Serve as a reserve of amino acids and nutrients for the developing plant
- Are mainly composed of prolamins (gliadins) and glutenins

These proteins are insoluble in water and, when hydrated, form a network that gives flour its viscoelastic properties.

This viscoelastic behavior is essential in the food industry, as it provides structure and texture to products such as dough and pasta.

Gluten was first described in 1742 by Giacomo Beccari, a professor at the University of Bologna. The term derives from the classical Latin *gluten*, meaning “glue,” “paste,” or “gum.” It was initially called *glutine*.

I-3-2 Composition

The endosperm of the wheat grain is a storage tissue mainly composed of starch granules embedded in a protein matrix consisting of: Gliadins ,Glutenins , Albumins , Globulins

Gluten is characterized by its method of extraction:

- When wheat flour is kneaded with about 50% of its weight in water, an elastic dough is formed.
- When this dough is washed under a thin stream of water, the starch and soluble proteins gradually dissolve and are removed.
- What remains is an insoluble, greenish, gelatinous substance called gluten.

The proteins of the wheat endosperm are classified according to their solubility:

- Albumins: soluble in water
- Globulins: soluble in saline solutions
- Gliadins: soluble in alcohol solutions
- Glutenins: insoluble in the above solvents but partially soluble in dilute acidic solutions

I-3-2 (continued) Protein Characteristics

The insoluble proteins that make up gluten (gliadins and glutenins) represent about 80 to 85% of the total proteins.

- Gliadins have a lower molecular weight than glutenins.

- Both gliadins and glutenins are hydrolyzed by enzymes during germination and seedling development, providing the amino acids necessary for growth.

These gluten proteins are characterized by:

- A high content of glutamic acid and proline
- A low content of basic amino acids, such as lysine, histidine, and arginine

I-3-3 Viscoelastic Properties

Gluten is responsible for the elasticity of kneaded dough as well as the chewiness of baked cereal products.

- When hydrated, gliadins are highly extensible and give the dough its:
  - Extensibility
  - Viscosity
  - Plasticity
- Glutenins, on the other hand, are responsible for:
  - Dough strength (tenacity)
  - Elasticity

High molecular weight glutenin subunits form polymers linked by disulfide bonds, which contribute significantly to gluten elasticity.

This viscoelastic property is essential in bread making:

- The CO_2 bubbles released during the anaerobic fermentation of sugars by yeast
- Are trapped within the gluten network, which is both elastic and strong
- This causes the dough to rise

II-1 – Primary Processing of Wheat: Milling and Semolina Production

II-1–1 – Cleaning and Preparation of Wheat for Milling

II-1–1–1 – Milling

Milling is the process aimed at separating the different parts of the wheat grain in order to obtain flour.

II-1–1–1–1 – Cleaning

Wheat usually comes from storage organizations where farmers gather their harvest. It is then purchased by millers, who must clean it before processing.

Cleaning is the process of removing all impurities present in the wheat, including:

- **Foreign materials**: stones, straw, metallic objects, etc.
- **Foreign grains**: grains from other cereals such as oats, maize, etc.
- **Dust**: dust lodged inside the crease of the grain, as well as dust adhering to the surface (bran) and, if possible, the fine hairs covering it

The different cleaning steps are as follows:

A.Wheat Reception

This is the first stage in the mill flow diagram. Once the wheat arrives at the mill, the trucks are weighed using a weighbridge. They are then directed to the sampling station, where a probe specifically designed for this purpose is used to ensure a representative sample from the entire height of the truck.

Based on the results obtained, the truck is directed to the receiving pit, where it can unload its contents. A pre-cleaning operation is then carried out to remove the largest impurities. This operation is performed through mechanical conveying using elevators.

B.Pre-cleaning

Pre-cleaning involves two main operations: separation based on magnetic properties and separation based on size.

- **Separation based on magnetic properties**: This process removes metallic particles from the wheat mass using magnets placed just before the cleaning separator and within the wheat flow.
- **Separation based on size**: This operation is carried out using a cleaning separator equipped with two layers of metal sieves. The first sieve removes large impurities (maize, broad beans, straw, etc.), while the second sieve removes sand. The movement and shaking of the wheat on the frames are generated by vertical vibrations produced by vibro-motors. These vibrations are effective due to the inclination of the frames. At the outlet of the cleaning separator, there is an aspiration channel.
- **Aspiration channel**: This is connected to a suction system that removes all impurities lighter than wheat. These impurities are then collected and extracted using a screw conveyor. Adjusting the airflow is very important; it must be strong enough to keep lighter-than-normal wheat grains suspended.

After pre-cleaning, the wheat is stored in pre-cleaned wheat silos. Once this stage is completed, the wheat awaits further preparation for cleaning, which is carried out through mechanical conveying.

C. Cleaning

The cleaning diagram in the mill is a very important stage, as it determines the quality of the wheat used for milling. At this stage, all particles smaller, larger, lighter, or heavier than wheat grains are removed.

Several steps are involved in the cleaning process:

- **Separation based on magnetic properties (magnetism)**: This step removes all metallic elements using a magnet.

- **Separation based on size**: This step removes impurities that are larger or smaller than wheat using a cleaning separator.
- **Separation based on density**: This separation is carried out using a destoner, which removes stones present in the wheat mass. The destoner eliminates impurities heavier than wheat. To ensure optimal operation, several parameters must be adjusted, such as vibration intensity and air suction.
- The vibration action creates waves within the product, which are enhanced by the airflow acting as a lifting force. During these waves, the product remains suspended for a longer time. Under the combined effect of these two phenomena, natural stratification occurs: lighter particles tend to move downward toward the discharge outlet, while heavier particles rise and are collected in a waste container.
- Adjusting this machine is not easy. The following parameters must be set:
- The vibration frequency of the upper frame plate;
- The choice of perforations in the upper frame plate;
- The suspension effect of the air passing through the wheat;
- The inclination of the working surfaces.

Separation based on shape (trieur / grading): This operation is performed by graders (trieurs). The round-seed grader removes impurities such as darnel seeds, vetch, and broken grains.

- A grader is a machine with indented (alveolated) metal cylinders:
- The first (upper) cylinder has alveoli with a diameter smaller than wheat grains (about 4 mm), which collect barley, round grains, and broken grains. These are then discharged via a screw conveyor as waste.
- Wheat and grains longer than wheat are directed to a second cylinder, whose alveoli have a larger diameter. Here, larger impurities are collected and removed through another screw conveyor.

Separation by friction: This operation is carried out using a dehuller (scourer or wheat brush), which has three main functions:

- To detach impurities adhering to the surface of wheat grains;
- To remove, by friction, fibrous parts loosened from the outer layers after the resting period;
- To crush foreign bodies present in the wheat (such as small clods of earth) and reduce microorganisms.

Brushing is performed using wheat brushes. The scourer is used at the final stage because it ensures the deepest cleaning of the grain by projecting the grains against surfaces

- Metal sieves, emery-coated surfaces or beaters, and brushes—arranged in either horizontal or vertical positions—ensure the removal of impurities adhering to the surface of wheat grains and, partially, those embedded within the crease. A small proportion of the outer layers of the grains (pericarp) may also be removed during these treatments by abrasion (grain against grain, or grain against metal or abrasive surfaces). This process also improves water penetration during conditioning (moistening).
- **Separation based on aerodynamic properties**: This is a separation principle by aspiration, which consists of exposing the wheat flow to an upward air current that carries away chaff debris, shriveled grains, and detached husk particles. This operation is carried out using an aspiration channel placed in parallel with two dehullers and the cleaning separator.
- **Wet cleaning (washing)**: Its purpose is to remove all dust and impurities that are either heavier or lighter than wheat grains. It also helps eliminate dust located in the crease that was not removed during brushing. Washing is carried out using a washer-centrifuge composed of two parts: a washing tank and a spin-drying column.

II-2–1–1–2 – Preparation of Wheat for Milling

- This operation is a very important step and requires a thorough understanding of the raw material. Wheat preparation consists of determining the amount of water needed and the required resting time. The quantity of water added depends on the type of wheat and the desired moisture content of the flour.
- After cleaning, wheat must be prepared in a way that facilitates the separation of the bran from the endosperm and the grinding of the latter. The process aims to achieve the following objectives:
- **Softening of the outer layers (bran)** to prevent their fragmentation and to facilitate their separation;
- **Reduction of the hardness of the endosperm** to promote its conversion into flour without damaging starch granules.
- To incorporate water, either an automatic dampener is used or the wheat is moistened manually using the following formula:
- $[(HF - HI)/(100 - HF)] \times D$

- Where:
- **HF** = Final moisture content
- **HI** = Initial moisture content
- **D** = Flow rate (kg/h)
- In practice, grain preparation before milling consists of controlled hydration (16–17%). Typically, the process involves:
- A first moistening followed by a resting period of 16 hours (in conditioning silos);

- Then a second moistening followed by a second resting period of 8 hours (in conditioning silos).

II-2-1-2 Semolina Milling

The main objective of **semolina milling** is the production of semolina, whereas the objective of **flour milling** is the production of flour.

This difference in purpose leads to several distinctions between the two processes, particularly in four key aspects:

- The type of wheat used
- Grain cleaning
- Preparation of wheat for milling
- The milling process

II-2-1-2-1 Type of Wheat

The most suitable wheat for semolina production is **durum wheat**, whose endosperm is vitreous (glassy in appearance).

When these wheats contain fully or partially floury grains (starchy or "mealy" kernels), their value for semolina production decreases for two main reasons:

- The semolina yield is lower.
- The appearance and quality of the semolina are reduced due to the presence of white, non-translucent particles.

II-2-1-2-2 Cleaning

The cleaning of durum wheat involves the same operations as that of soft wheat. However, certain precautions must be taken during some cleaning stages:

- During sorting, it may be necessary to complement the standard equipment with a **densimetric separator**, which operates on a different principle.
- Since the germ is difficult to separate from semolina during milling, efforts are made to remove as much of it as possible beforehand through **de-germing (pearling**

II-2-1-2-3 Preparation of Wheat for Milling

In soft wheat milling, the goal is to deeply moisten the grain.

In semolina milling, however, the vitreous nature of the endosperm must be preserved. Therefore:

- Only a moderate amount of water is added.

- This is followed by a shorter resting time, often less than 12 hours.

This allows the water to soften the bran without excessively moistening the endosperm.

II-2-1-3 Influence of Moisture on Milling

Case of Moist Milling

- Sieving becomes difficult due to clogging of the sieving equipment.
- Bran cleaning is difficult because flour particles strongly adhere to bran particles.
- The resulting flour is moist and may deteriorate easily.

Case of Dry Milling

- Separation of the endosperm from the bran is difficult, leading to loss of small endosperm particles in the bran.
- The resulting flour is too dry and does not meet quality standards.

II-2-2 Wheat Milling

Milling, the central operation in the transformation of wheat into flour and semolina, relies on two main unit operations:

1. **Fragmentation-Dissociation of the Grain**
   - Separates the endosperm from the bran (grinding)
   - Breaks down coated semolina (disintegration)
   - Reduces the endosperm into flour (conversion)
2. **Separation of Components**
   - Ensures the separation of bran and other outer layers based on particle size (sieving)
   - Uses aerodynamic properties for semolina purification (air classification)

II-2-2-1 The Different Phases of Milling

1. Grinding (Broyage)
Grinding dissociates the endosperm from the peripheral parts of the grain (bran and aleurone layer) by crushing and shearing between grooved rollers.

- The rollers rotate in opposite directions at different speeds, with a speed ratio of approximately 2.5.
- Grooves have a small face (cutting edge) and a large face (back), characterized by their depth, the angle between faces, and the flat section separating each indentation.

- The relative positioning of the grooves significantly affects the characteristics of the products obtained after grinding.

2. Disintegration and Conversion (Claquage et Convertissage)
These operations are performed using smooth-roller machines:

- **Converters**: Treat purified semolina
- **Disintegrators (Claqueurs)**: Treat coated semolina

Both processes reduce the particle size of semolina, but differ based on the origin and nature of the product they process.

3. Air Classification (Sassage)
Sassage separates milling products based on shape, size, and density:

- Products are suspended by an upward airflow beneath sieves with progressively smaller mesh widths.
- The sieves move in a reciprocating and tilting motion.
- Particle segregation depends on density and aerodynamic properties: starch-rich endosperm particles, being denser than bran particles, fall faster onto the sieves and are extracted first.

4. Sieving or Bolting (Tamisage / Blutage)

- Sieving separates products (semolina, flour, bran) coming from smooth and grooved rollers according to particle size.
- It is carried out in **plansichters**, machines composed of stacked sieves subjected to continuous rotational and reciprocating motion, powered by an eccentric motor.

Disintegration (Désagrégage)

Disintegration is an operation that **breaks down coated semolina** by removing bran fragments that adhere to the endosperm.

- Semolina rejected at the air classifier (sasseur) is called **coated semolina**.

Detachers (Détacheurs):

- There are two types: **drum-type** and **percussion-type**.
- During milling with smooth rollers, small **flour flakes** form.
- These flakes are rejected by the flour sieves in the plansichters and accumulate in the tailings passages of the mill.
- While these flakes enrich the tailings products, they **reduce overall yield** and create unnecessary load in the passages.

- The function of the detachers is to **disaggregate these flour flakes** without breaking down bran or germ particles.

Sequence of Operations in Flour and Semolina Production

The process for producing **soft wheat flour** and **durum wheat semolina** can be summarized as follows:

- **Flour Milling (Soft Wheat)**
    1. Wheat is first sent to a **grinder**, where it is broken into fragments of varying size.
        - These fragments consist of:
            - Pure endosperm pieces
            - Endosperm still covered by bran layers
            - Bran fragments without endosperm
    2. Fragments are then sent to **plansichters**, where the first sorting occurs based on fragment size.
    3. Air classification (sassage) is only used occasionally.
- **Semolina Milling (Durum Wheat)**
    1. Milling is organized around **air classifiers (sasseurs)**, which ultimately isolate purified semolina.
    2. Due to the particle size of semolina, it is **not possible to separate the endosperm from bran using simple sieving**, unlike soft wheat flour, which is much finer than the bran fragments.

Tableau 13 – Principaux matériels utilisés en meunerie.

Cylindre lisse	rouleau métallique dont la surface est sans aspérité.
Cylindre cannelé	rouleau métallique en surface duquel ont été gravées des cannelures. Celles-ci sont des sillons asymétriques régulièrement tracés en surface des cylindres, dans le sens de la longueur, et dont la largeur et la profondeur peuvent être respectivement comprises entre 800-2 500 et 200-600 µm.
Broyeur, réducteur et désagrégeur	machines constituées de deux cylindres cannelés entraînés en sens inverse et à des vitesses différentes (rapport des vitesses :1/2,5). L'écartement entre les deux cylindres est réglable.
Claqueur et convertisseur	machines identiques aux broyeurs, à l'exception des cylindres qui sont lisses. Ils ne sont pas utilisés en semoulerie.
Plansichter	machine constituée de tamis superposés et soumise à un mouvement de rotation (environ 200 tr/min(1)) destiné à assurer une progression régulière des produits d'un tamis à l'autre.
Sasseur	machine constituée de tamis inclinés soumis à un mouvement de va-et-vient et d'un système d'entraînement des produits par l'air permettant de les séparer sur la base de leurs propriétés aérodynamiques (forme, taille et densité).

(1) tr/min = tours par minute.

Tableau 15 – Différents types d'appareils à cylindres.

Type	Nature des cylindres	Rapport de vitesse	Usage principal
Broyeurs	cannelés	1 : 2,5	blés tendres et blés durs
Claqueurs et convertisseurs	lisses	1 : 1,25	blés tendres
Réducteurs et désagrégeurs	cannelés	1 : 2,5	blés durs

Tableau 16 – Effet de la position des cannelures des cylindres sur les résultats du broyage.

Position des cannelures	Effets
Tranchant contre tranchant	production de semoule, gruau et farine
Tranchant contre dos	production d'une partie de grosse semoule pour deux parties de semoules moyennes, une de finot(1) et une de farine
Dos contre tranchant	production de semoule moyenne, de finot et de farine plate(2)
Dos contre dos	production importante de farine (la compression est maximum)

(1) Les finots sont les fines semoules de broyage. (2) Les farines plates sont les farines de queue de mouture.

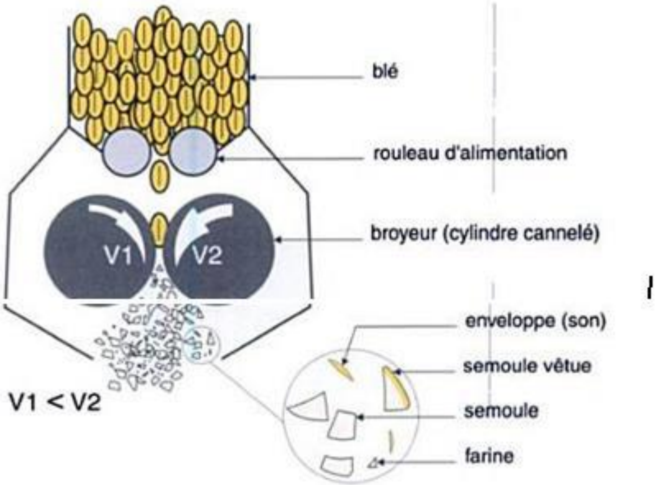

Figure 6 – Principe de fonctionnement d'un broyeur à cylindre.

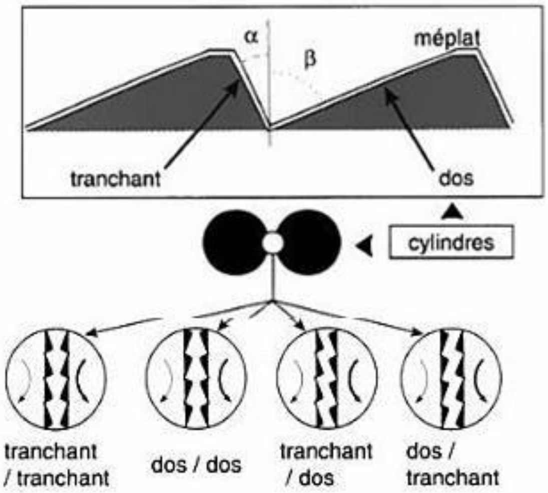

Figure 7 – Caractéristiques et positionnement des cannelures.

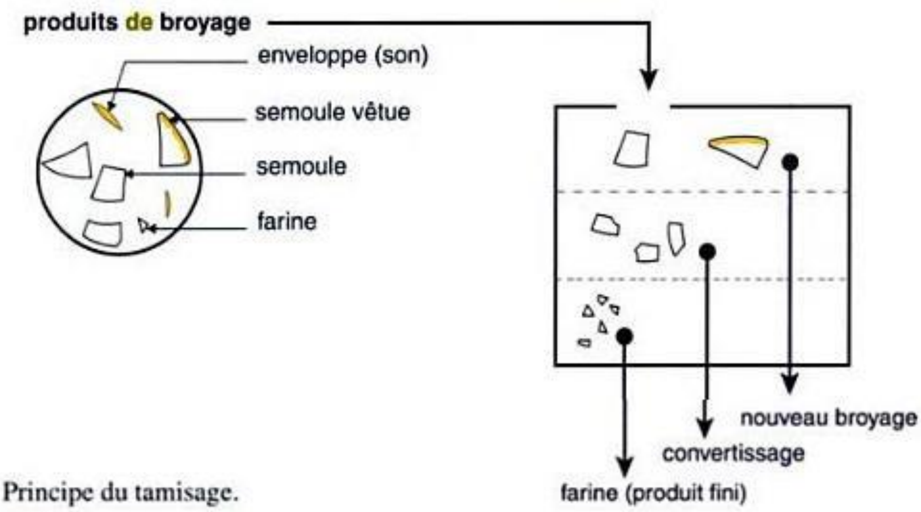

Figure 8 – Principe du tamisage.

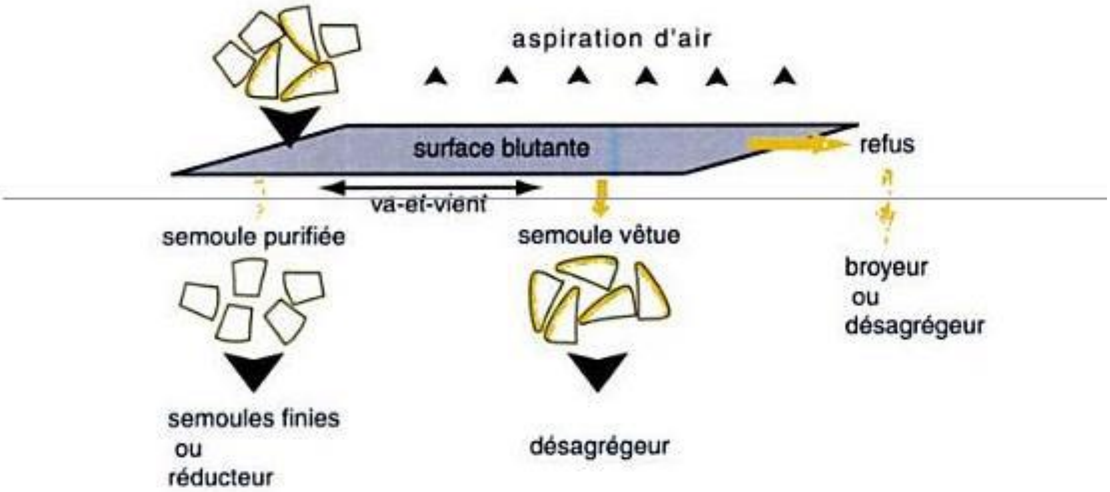

Figure 9 – Principe du sassage.

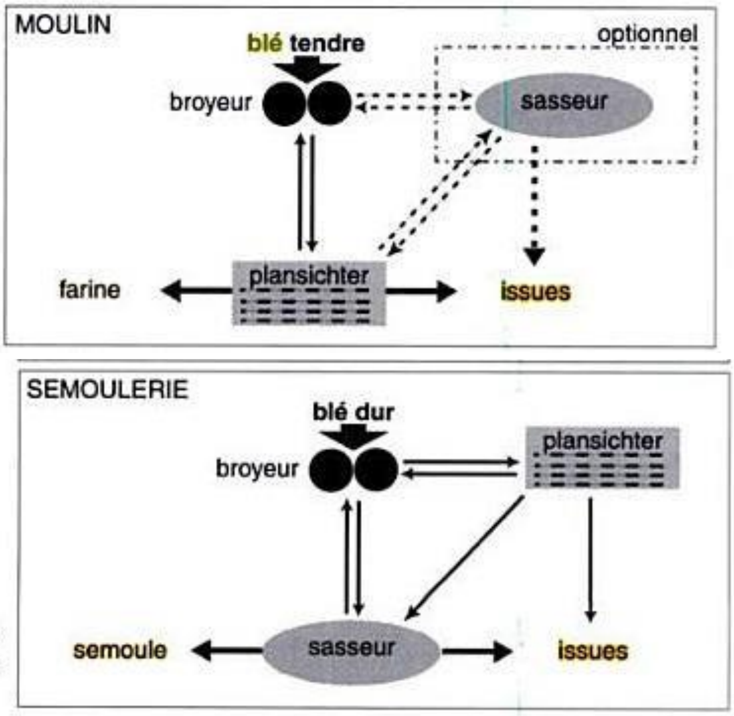

Figure 12 – Principes comparés de la meunerie et de la semoulerie.

Figure 9 – Principe du sassage.

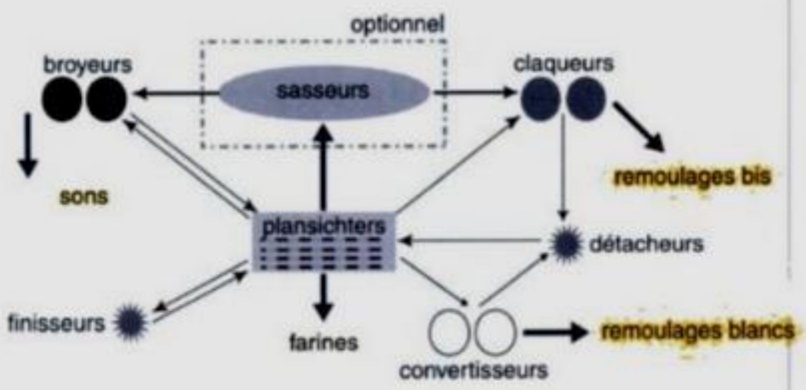

Figure 10 – Principe de la mouture du blé tendre.

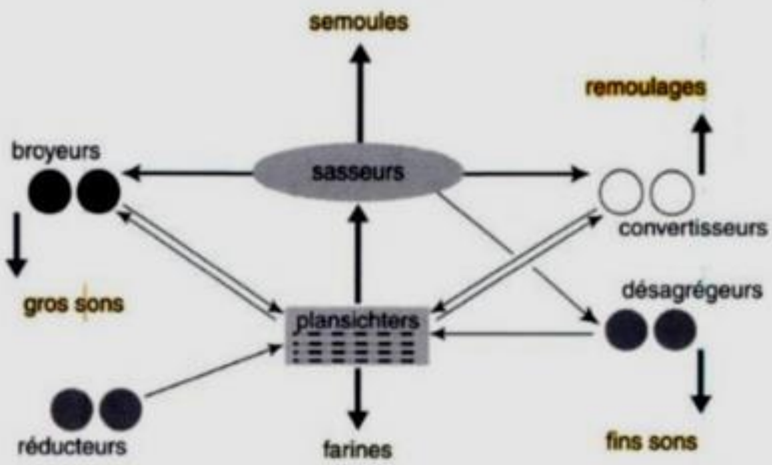

Figure 11 – Principe de la mouture du blé dur.

II-2-2 The Different Milling Products

1. Flour

- The main product of milling, consisting of very fine endosperm particles ranging from **15 to 200 µm**.

2. Semolina

- Particles of mostly pure endosperm, sometimes containing a small percentage of bran.
- Particle size ranges from **250 to 1,000 µm**.
- Includes **coarse semolina** and **fine semolina**, also called **purified or coated semolina**.

3. Fine Semolina (Finots)

- Fine endosperm particles resulting from grinding, intermediate in size between fine semolina and flour.

4. Gruels (Gruaux)

- Similar to finots, produced during the reduction of semolina at the **head of the disintegrators and converters**.

5. Milling By-products (Issues)

Other products besides flour include:

- **Bran (Sons):**
    - Consists of the outer layers of the grain and some endosperm adhering to the inner surfaces of these layers.
    - Classified by size: **coarse bran** and **fine bran**.
- **Re-milled Products (Remoulages):**
    - Composed of a mixture of more or less finely ground bran and floury endosperm.
    - Types include:
        - **Coarse remoulages (Remoulages bis):** The largest fraction, representing the final rejection from the disintegrator.
        - **White remoulages (Remoulages blancs):** The finest and richest in flour, collected at the end of the conversion process.