People's Democratic Republic of Algeria
Ministry of Higher Education and Scientific Research
University 8 Mai 1945 Guelma

Faculty of Natural and Life Sciences and Earth and Universe Sciences
Department of Ecology and Environmental Engineering

Course Handout in:

Technology of Agri-Food Industries 2

Intended for third-Year Bachelor's Degree students in Agri-Food Technology and Quality Control

Developed by:

Dr. BENHALIMA Lamia

2025

PREFACE

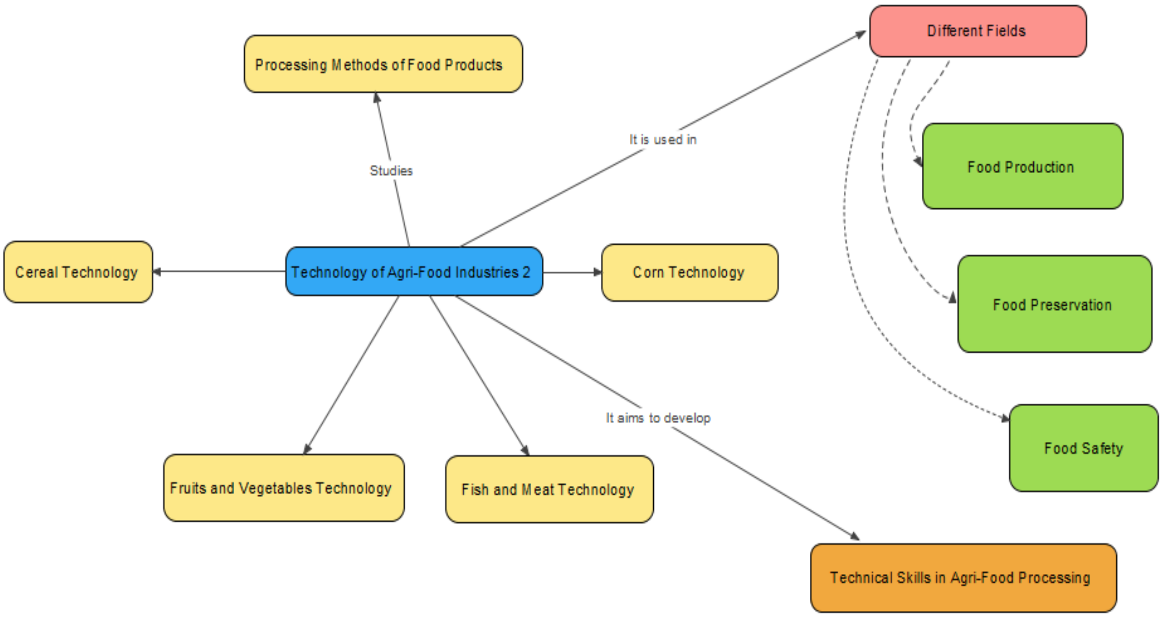
Several raw materials must undergo technological transformations to produce commercialized finished products. Generally, these processes are standardized and rigid. Both classic and modern methods are used, allowing for better utilization of the raw material's dry matter.

The *Technology of Agri-Food Industries 2* course provides students with a comprehensive understanding of food processing techniques in the cereal, fruit and vegetable, meat, and fish industries. The course covers fundamental principles, industrial processes, and quality evaluation methods for various food products. Students will be able to analyze and apply different food processing techniques, evaluate food quality, and understand the technological advancements in agri-food industries.

In line with this objective, in addition to the twice-weekly *Technology of Agri-Food Industries 2* course taken by students at the University of 8 May 1945, Guelma, tutorials and practical work are distributed to allow students to learn the different methods for assessing the quality of cereal products, fruits and vegetables, as well as meat and fish-based products.

This course is intended for third-year students in Agri-Food Technology and Quality Control during the second semester of the academic year. Its content aligns with the official curriculum of the Technology of Agri-Food Industries 2 course. It has been written to provide a study and reference tool that covers the required knowledge.

Importance and fields of application of the subject



Targeted skills

The targeted skills for students after completing this course are:

- Understand the structure and composition of cereals;
- Master cereal processing techniques ;
- Evaluate cereal quality ;
- Understand fruit and vegetable processing technologies;
- State the principles of canning;
- Explain the various unit operations involved in canning;
- Describe the canning process of fruits and vegetables;
- Acquire skills in meat and fish technology;
- Apply preservation methods for perishable foods.

Pre-requisites

The prerequisites for this course consist of having sufficient basic knowledge acquired in the following area:

- Chemistry
- Biochemistry
- Microbiology,
- Physics and thermodynamics,
- Energy sciences, etc.

Course outline

The content of this course is organized into three chapters:

- The first chapter delves into the world of cereal technology;
- The second chapter explains the different preservation processes of fruits and vegetables products;
- The third chapter is dedicated to processing of meat and fish products.

Practical work

There will be several practical sessions covering different processing techniques, along with educational field trips to various industries.

Tutorials

There will also be tutorial sessions where students will analyze case studies, work on exercises, and give presentations related to the previously mentioned chapters.

Evaluation

Final examination: 60%.

Continuous control (Practical works, Reports, other): 40%.

Table of contents

Table of contents

Table of contents

List of Figures

List of Tables

Part 1

CEREAL TECHNOLOGY

PART 1: CEREAL TECHNOLOGY

INTRODUCTION

- **Cereal classification**

Cereals are food grains belonging to 10 plant species, the 3 most widely used today: wheat, rice and maize; barley, rye, oats, sorghum, meslin (mixture of wheat and rye), triticale (hybrid of wheat and rye). Wheat is grown all over the world, with 2 species in particular: durum wheat (*Triticum durum*), the semolina wheat par excellence and common wheat (*Triticum oestivum*).

Most cereals belong to the ***Gramineae*** (or *Poaceae*) family. These are: Soft wheat, Durum wheat, Barley, Oats, Rye, Corn, Rice, Sorghum, Millet. Some belong to the ***Festucoidae*** subfamily: Wheat, Barley, Oats, Rye; others belong to the ***Panicoideae*** subfamily: Corn, Rice, Sorghum, Millet. One cereal, buckwheat, belongs to another family, ***Polygonaceae*** (Wrigly *et al.,* 2017).

- **Cereal sectors**

World cereal production is estimated at 2 billion tons, an increase of around 800 million tons on 1970, corresponding to annual growth of around 1.7%, an order of magnitude comparable to that of world population growth. Maize (605 million tons), wheat (600 million tons) and rice (600 million tons) come out on top, together accounting for 90% of this total. Barley production is around 150 million tons, sorghum 60 million tons and all other cereals around 100 million tons. The share of certain cereals, such as oats and rye, is gradually becoming marginal. However, millet is still grown in Africa. China and NAFTA (Canada, Mexico, and USA) each produce around 450 million tons, accounting for over 40% of world production. India and the European Union follow with 220-230 million tons each. ASEAN (South-East Asia), South America, Africa and the former USSR all have production levels of between 100 and 130 million tons. France, with a cereal production of 65 million tons, is the largest producer in the European Union. It is followed by Germany and the United Kingdom (Reeves *et al.,* 2015).

The global area devoted to cereals is around 700 million hectares, i.e. around half of all land devoted to crops (FAO "Arable lands" classification) in the world. With 220 million hectares, wheat is the most widely grown cereal in the world. Maize and especially rice are more concentrated geographically, due to their climatic requirements. Around 135 million hectares are devoted to maize and 140 million to rice. The average yield for all cereals combined is around 2.8 tons per hectare, with a fairly wide dispersion around this average: around 2 tons/ha for barley, 2.5 tons/ha for wheat and between 3.5 and 4 tons/ha for maize and rice.

The increase in production over the last thirty years is due not only to the increase in cultivated area, but above all to the rise in yields as a result of the technical progress achieved over the last few decades: varietal improvement, growing use of fertilizers, methods of combating crop pests, mechanization, irrigation, and so on. A comparison between the world average yield and those of the most advanced countries (6 to 7 tons/ha) shows that there is still considerable room for improvement.

Wheat (over 100 million tons traded) and maize (around 70 million tons traded) account for the bulk of international cereal trade. Rice, widely consumed in its areas of production, accounts for just low than 10% of this trade (25 million tons), on a par with barley (20 million tons) (Godon *et al*., 1998).

In Algeria, winter cereals form the basis of the daily diet. National productivity is fairly low, at around 08 to 10 qx/ha (yield unit: quantity of product harvested/area cultivated), and this is reflected in the huge gap that has opened up between supply and demand. Most of these crops are grown in the regions of Sidi Bel Abbés, Tiaret, Sétif and El Eulma. Most of these major cereal-growing regions are located on high plateaus. These are characterized by cold winters, irregular rainfall, spring frosts and hot, drying winds. Despite the efforts made, yields remain very low. Their low level is often explained by the influence of poor pedoclimatic conditions; however, these conditions can be associated with, among other things, poor mastery of cultivation techniques.

- **Cereal utilization worldwide**

Cereals are, from both a strategic and historical perspective, the most important crop. They play a vital role in maintaining the nutritional balance of populations across all continents. Cereals are primarily used for human consumption, especially wheat and rice, and serve as a key raw material in food production. They are also widely used in animal feed. A smaller portion is industrially processed to produce starch and alcohol. The way cereals are utilized varies depending on factors such as availability, standard of living, consumer habits, the level of development of the processing industry, trade, and other economic and cultural influences (Kučerová, 2015).

- **Human nutrition**

Rice is the most important cereal crop in the developing world, constituting the staple food for more than half the world's population. Among cereals, rice production uses the largest proportion of land. Corn provides nutrients for humans and animals, and serves as a raw material for the starch industry. As well as starch, cereal flours contain water-insoluble reserve proteins, prolamins and glutenins, which are not found elsewhere. When present in the right proportions, they enable us to obtain an extensible dough (properties of prolamins) and an elastic dough (properties of glutenins).

Only two cereals are suitable for bread-making: wheat and rye. The other cereals are used in a variety of food applications, the most common being the preparation of alcoholic beverages, but the most common uses for cereals are in cooking, either directly as grain, flour, starch or semolina (Akbar, 2020).

- **Animal nutrition**

A large proportion of the world's cereal production is used to feed livestock: in developed countries, 56% of cereal consumption is used to feed livestock and 23% in developing countries. Worldwide, 37% of cereal production is used to feed livestock.

Virtually all cereals are used in animal feed, even wheat traditionally reserved for human consumption, in a variety of forms:

- Whole seeds;
- Whole plants harvested before maturity, in the form of silage (a method of preserving fodder by wet lactic fermentation: the result is acid fodder with a moisture content ranging from 50 to 85%): corn and sorghum.

- **Industrial applications**

While the main outlet remains human and animal foodstuffs, certain species (wheat, corn) are also being put to industrial use: the starch derived from their grains is used as a (renewable) raw material for the manufacture of various non-food compounds:

- Production of ethyl alcohol and alcoholic beverages by fermentation and distillation;
- Starch derivatives, syrups, dextrose, dextrin, polyols... mainly derived from corn, and used in the food, paper, pharmaceutical and other industrial sectors;
- Corn cobs (the cob is the stalk of the corn cob) can be processed to produce ethanol, which can be used as a biofuel (Wrigley and Taylor, 2023).

Example: Ethanol production

$$(C_6H_{10}O_5)n \xrightarrow{\text{Enzymes}} C_6H_{12}O_6 \xrightarrow{\text{Yeast}} 2CH_2H_5OH + 2CO_2$$

Strach Glucose Ethanol Carbone dioxide

I. CEREAL GRAINS

1. Structure

1.1. Histological structure

Understanding the structural organization of industrially significant cereal grains is essential for various facets of cereal processing technology, including the milling of common and durum wheat, the processing of maize and rice, and the malting of barley. In these applications, detailed knowledge of the three-dimensional architecture of cereal tissues and the spatial distribution of their components is of critical relevance.

In general, members of the *Gramineae* family produce dry, one-seeded fruits commonly referred to as grains. However, in strict botanical terms, these fruits are classified as caryopses. The wheat caryopsis consists of a fruit coat (pericarp) and a seed. The fruit coat is tightly fused to the seed coat, which encloses the rest of the seed. The seed itself is composed of the embryo (or germ), the endosperm, the nucellar epidermis, and the seed coat. The endosperm is surrounded by both the nucellar epidermis and the seed coat.

Cereal grains are made up of 3 main parts: the germ, the albumen and the envelopes (Fig.1) (Delcour and Hoseney, 2010):

- Envelopes are made up of four tissues: the outer pericarp, the inner pericarp, the testa and the nucellar layer or hyaline band. These envelopes and the aleurone layer are composed mainly of polysaccharides (arabinoxylans, xyloglucans and cellulose):
  - **The outer pericarp**, 15-30µm thick, corresponds to the epicarp and consists of two tissues made up of dead cells: the epidermis and the hypodermis. The epidermis is made up of elongated cells measuring 80 to 300µm and arranged along the embryonic axis. The hypodermis has the same structure as the epidermis, and is strongly adherent to it. The innermost layer of the outer pericarp is made up of remnants of thin-walled cells. Due to their discontinuous cellular structure, this layer forms a natural cleavage plane. As a result, the beeswing is often removed prior to milling.

- **The inner pericarp** corresponds to the endocarp and mesocarp, made up of tubular cells and cross cells respectively. Crossed cells are perpendicular to the grain's longitudinal axis, while tubular cells are parallel to it. Crossed cells vary in size, averaging 150µm long by 20µm wide.

  The pericarp prevents water loss during grain development, but does not prevent water penetration. The dead cells of the pericarp are able to retain water and increase the weight of the grain by 4-5% after only a few minutes of soaking.

- **The testa** corresponds to the spermoderm (protective envelope of the seed and embryo). Its inner surface rests on the cuticle (outer layer covering the aerial organ) of the hyaline layer. It consists of two compressed, lipid-rich cuticles made up of elongated cells measuring between 120 and 190µm in length and 20µm in width, which fuse with a pigmentary film. The axes of the cells in these two layers are perpendicular; one parallel to the sulcus, the other perpendicular to it. The testa is described as highly hydrophobic.

- **The nucellar layer or hyaline band** corresponds to the perisperm (tissue derived from the nucellum (the inside of the ovum) and which provides the embryo with the substances necessary for its development). It is about 20µm thick. It is made up of a compacted cell base due to the filling of the starchy albumen and the development of the embryo (Fulcher and Wong, 1980). It is composed of cells between 30 and 200µm long and 15 to 40µm wide. This layer is lined with a thin cuticle that connects it to the aleurone layer, also known as the nucellar lysate layer. This hyaline band is highly hydrophobic and seems to play an important role in the circulation of water between the inside and outside of the seed.

  In wheat, a single aleurone layer surrounds the starchy albumen. Together with the germ, it is the only part of the kernel made up of living cells. The cells of the aleurone layer are polygonal in shape and measure approximately 65µm. They have large nuclei and thick walls (up to 8µm), and are rich in vitamins (B1, B2, B3, B6, B9 and E) and minerals (P, K, Mg, Mn and Fe). The aleurone layer is rich in metabolites and has a nourishing role, while its structure plays a protective role.

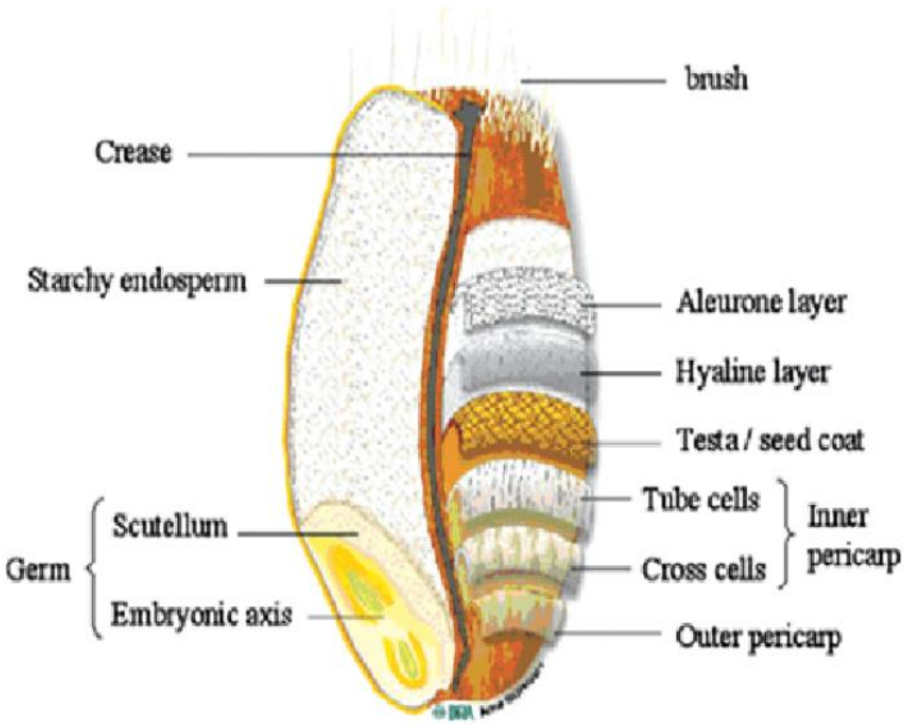


Figure 1: Histological section of a wheat grain (Brouns *et al*., 2012).

- **The germ:** The germ results from the fusion of male and female gametes. It is made up of the embryonic axis, which gives rise to the tigelle, the mesocotyl (which gives rise to the stem during germination) and the radicle (the emryonic form of the root), and the scutellum, which gives rise to the cotyledon (the primordial leaves). The germ is the part of the grain with the highest moisture content and lipid concentration. Proteins in the germ are albumins and globulins and represent around 35% of dry matter.

- **The albumen** is the grain's most important compartment, representing around 80% of its weight. It is the grain's reserve tissue. The starchy albumen is essentially made up of starch granules embedded in a protein matrix. The cells of the starchy albumen have thin walls and can be classified into three main groups:

- Peripheral cells located beneath the aleurone layer and measuring 60µm.
- The prismatic cells (the most superficial) located beneath the peripheral cells, measuring between 128-200µm long and 40-60µm wide.
- Cells located in the central part of the albumen that are rounded or polygonal in shape measuring between 72-144µm long and 69-120µm wide.

2. Composition

2. 1. Average composition

If we look at the whole grain of various cereals, we see a great deal of similarity in their chemical composition, but also some differences (Kučerová, 2015):

- **Water**: Cereal grains are particularly dehydrated plant organs, with an average moisture content of 14%, a decisive factor during storage. It is difficult to store grains with moisture content above 17-18%, and virtually impossible above 23%. The most favorable grain moisture content for storage is 10-15%; moisture levels below 9% may be necessary for prolonged storage at 20°C. Water conditions the speed and intensity of chemical and enzymatic reactions, as well as microbial development.

- In all species, grain is essentially **carbohydrate**-based, with 60 to 75% digestible carbohydrates (mainly starch). Cereals thus appear as essentially energy-dense foods: 330 to 385 kc/ l00 g. The amount of free monosaccharides in mature cereal grains is low, primarily consisting of pentoses and hexoses. Oligosaccharides, such as sucrose, maltose, and raffinose, are present in small concentrations. From a technological perspective, the most important group, alongside proteins, is polysaccharides, which serve both storage and structural functions. Starch, the storage polysaccharide, is the most significant component of the grain, found in the endosperm. The state of starch and the activity of amylases influence the quality of bread and baked goods, particularly the texture of the crumb and the color of the crust. Starch content ranges from 55 to 75% of the dry grain, depending on species and variety. The starch content in flour, which is mainly composed of endosperm, is higher (about 80%).

- Dietary **fiber** content varies from 2% to over 30%. It depends in particular on grain size, with smaller grains (small mils) having a higher proportion of husks.
  A positive characteristic of fiber is its beneficial effect on the physiological function of the digestive system. It supports healthy colon function, forms gel-like structures, swells, and provides a sense of fullness more quickly, without increasing caloric intake. Fiber slows the absorption of sugars and reduces the absorption of dietary fats, leading to a decrease in blood sugar levels and cholesterol, thereby lowering the risk of cardiovascular diseases. It also has a positive impact on the balance of bile acids and provides beneficial effects in the diets of diabetic individuals by regulating blood sugar levels and lowering the glycemic index of carbohydrate-rich foods.

- **Protein** content ranges from 6 to 18% in extreme cases, but is usually between 8 and 13%. Qualitatively, these proteins are mediocre: the limiting amino acid is lysine; in the case of maize, tryptophan is also severely deficient and constitutes the secondary limiting amino acid. The concentration of sulphur amino acids is higher in legumes, which supplement each other in this way.

- **Lipids** are relatively scarce, but they are extremely interesting thanks to the high proportion of polyunsaturated fatty acids.

- Cereals are poorly mineralized: phosphorus content is high, calcium content is low (except for eleusine), and is not sufficient to neutralize all the phytic acid. Phytic acid also insolubilizes Mg, Zn and Fe.

- With the exception of yellow corn, which contains active carotenoids, cereals have no vitamin A activity. Vitamin C is also lacking. Sprouts are rich in vitamin E. Group B vitamins are present (with the exception of vitamin B12).

2.2. Distribution of constituents in the grain

- **The outer layers (pericarp and tegument = testa)** are characterized primarily by their content of :
  - Not insignificant in protein (7%), lipids (2%), minerals and B vitamins (with the exception of vitamin B12, absent from the plant kingdom);
  - Very high in fiber, which plays an important physiological role in the normal progression of the alimentary bolus through the digestive tract, and promotes certain metabolisms (cholesterol, triglycerides). But it also plays a very important role in reducing the digestibility of other ration components, notably proteins.

- **The aleurone layer** is extremely rich in nutrients. In the case of wheat, for example, although it accounts for only 6% of the grain's weight, it alone contains :
  - 16 to 20% of whole-grain protein
  - 31% of lipids - 58% of minerals
  - 32% of thiamine (vitamin B1)
  - 37-82% of other B vitamins.

  Because of its high concentration of noble nutrients, the aleurone layer is sometimes called the marvelous layer. However, it also contains a significant amount of phytic acid (insolubilizing proteins and minerals such as Ca, Mg, Fe, Zn) and fibers, which reduce the digestibility of ration constituents. From a histological point of view, the aleurone layer belongs to the albumen, but as it adheres strongly to the outer husks, it follows the latter during hulling to form the bran (Brouns *et al.*, 2012).

- **The germ** is rich in minerals, proteins, lipids and vitamins. Depending on the cereal, it may contain a large proportion, or even most, of the lipids and fat-soluble vitamin E. The scutellum is very rich in thiamine.

- **The albumen** contient contains mainly starch embedded in a protein matrix composed mainly of prolamins (gliadins, high and low molecular weight glutenins), but also of albumins and globulins. These two protein families, glutenins and gliadins, are hydrolyzed during germination by enzymes produced in the embryo and the aleurone layer. They are the source of amino acids needed for seed germination; their protein, lipid, mineral and vitamin contents are lower than those of the germ and husks. Moreover, the nutritional quality of its proteins is inferior to that of the proteins in the peripheral parts of the grain (Delcour and Hoseney, 2010).

Table 1 gives an overview about the nutritional composition of the main cereal grains.

Table 1: Nutrient composition of cereal grains (Devi *et al*., 2014).

Cereals	Protein (%)	Fat (%)	Crude fiber (%)	Ash (%)	Starch (%)	Total dietary fiber (%)	Total phenol (mg/100 g)
Wheat	14.4	2.3	2.9	1.9	64.0	12.1	20.5
Rice	7.5	2.4	10.2	4.7	77.2	3.7	2.51
Maize	12.1	4.6	2.3	1.8	62.3	12.8	2.91
Sorghum	11	3.2	2.7	1.8	73.8	11.8	43.1
Barley	11.5	2.2	5.6	2.9	58.5	15.4	16.4
Oats	17.1	6.4	11.3	3.2	52.8	12.5	1.2
Rye	13.4	1.8	2.1	2.0	68.3	16.1	13.2
Finger millet	7.3	1.3	3.6	3.0	59.0	19.1	102
Pearl millet	14.5	5.1	2.0	2.0	60.5	7.0	51.4
Proso millet	11	3.5	9.0	3.6	56.1	8.5	–
Foxtail millet	11.7	3.9	7.0	3.0	59.1	19.11	106
Kodo millet	8.3	1.4	9.0	3.6	72.0	37.8	368

II. WHEAT

Phylum: *Spermaphytes*

S/Branch: *Angiosperms*

Class: *Monocotyledons*

Superorder: *Commiliniflorales*

Order: *Poales*

Tribe: *Triticeae*

Family: *Poaceae*

Genus: *Triticum*

Three groups of wheat are known according to chromosome number:

- The diploid group (2*7 chromosomes) (oldest cultivars)
- The tetraploid group (4*7 chromosomes), including durum wheat
- The hexaploid group (6*7 chromosomes), including soft wheat

1. Wheat protein properties

White wheat flour generally contains about 1% less protein than the whole wheat from which it is milled. Since flour accounts for just over 70% of the total milling output, this indicates that the remaining fraction—known as mill-feed—has a significantly higher protein content than the milled endosperm. The proteins found in the pericarp and the aleurone layer, which are the main components of mill-feed, do not contain any gluten proteins (Delcour and Hoseney, 2010).

Osborne, in 1907, was the first to take an interest in the classification of wheat grain proteins. In 1924, he defined four groups of proteins characterized by their solubility in different media:

- Albumins, which are soluble in water;
- Globulins, which are soluble in saline buffers;
- Gliadins are soluble in 70% alcohol;
- Glutenins, which are soluble in bases, acids or detergents in the presence of a reducing agent.

This classification was revised in 1986 by Shewry and colleagues, who proposed two broad categories:

- Metabolic proteins: albumins and globulins, amphiphiles;
- Reserve proteins: gliadins and glutenins.

Proteins can exist as simple proteins, composed solely of polypeptide chains, or as conjugated proteins (proteids), which include additional non-protein substances within their molecular structure. In cereals, these include glycoproteins, which contain carbohydrate components, and lipoproteins, which contain lipid components. Simple proteins are categorized based on their functional properties into protoplasmic proteins (such as albumins and globulins), primarily located in the germ and aleurone layer, and storage proteins (such as prolamins and glutelins), which make up a significant portion of the cereal grain (Kučerová, 2015).

1.1. Metabolic proteins (soluble/cytoplasmic)

a) Albumins and globulins

Albumins and globulins represent 15-20% of the proteins present in wheat flour, and are soluble in water and saline buffers respectively. This group of proteins is highly diverse in terms of physicochemical properties (amino acid composition, molecular weight). These proteins are involved in grain formation and the accumulation of reserves in the albumen.

b) Amphiphilic proteins

Amphiphilic proteins represent between 5 and 9% of the proteins present in wheat flour. They have both hydrophobic and hydrophilic poles. These proteins are soluble in the detergent Triton X114 and are bound to membranes. They play an important role in quality, particularly puroindolines (flour texture proteins), which are known to have an effect on the technological properties of dough (Reynolds and Braun, 2022).

1.2. Reserve proteins

Reserve proteins are part of the prolamins and are made up of a complex mixture of proteins. These proteins have been extensively studied for their relationship with the technological quality of wheat.

Prolamins include both monomeric proteins (gliadins) and polymeric proteins (glutenins), which are themselves made up of two subgroups: high-molecular-weight glutenin subunits (SG-HPM) and low-molecular-weight glutenin subunits (SG-FPM). Generally speaking, the proportion between these different prolamins is as follows: 40% gliadins, 40% SG-FPM and 20% SG-HPM.

These proteins have also been classified according to their composition and sequence. A distinction is made between:

- Sulfur-rich prolamins account for 70% of prolamins and are made up of gliadin types α, β, γ and SG-FPM.
- Sulfur-poor prolamins account for between 10 and 12% of total prolamins and are made up exclusively of ω-type gliadins.
- High-molecular-weight prolamins account for 20% of prolamins. SG-HPMs can be of two different types: x and y. These prolamines have the ability to form polymeric structures with SG-FPM and certain gliadins via disulfide bridges. The mass of the polymerized network, depending on the glutenin and gliadin alleles, ranges from 600,000 Da to over 107 Da (dalton: unit of atomic mass = 1.661 $*10^{-24}$g).

In terms of biological value, protoplasmic proteins have an optimal amino acid composition; however, their low abundance in cereal grains results in a generally low overall biological value of cereals. Regarding the biosynthesis of the different protein fractions in wheat, structural proteins (albumins and globulins) are synthesized first, followed by glutelins, with protamines being produced at the final stage (Kłosok *et al.*, 2021).

- **Gluten**

Gluten is a cohesive and viscoelastic network formed during the mixing process, playing a key role in determining dough and bread quality. It consists of two main protein types: gliadins, which are soluble in alcohol, and glutenins, which are insoluble (Fig. 2). These proteins are notably rich in glutamine (35%), glycine (20%), and proline (10%), while containing low levels of amino acids with charged side groups. Gluten is often described as a "two-component adhesive," where gliadins serve as a plasticizer for glutenins. From a technological perspective, gliadins enhance the dough's viscosity and extensibility, whereas glutenins provide strength and elasticity (Klosok *et al*., 2021).

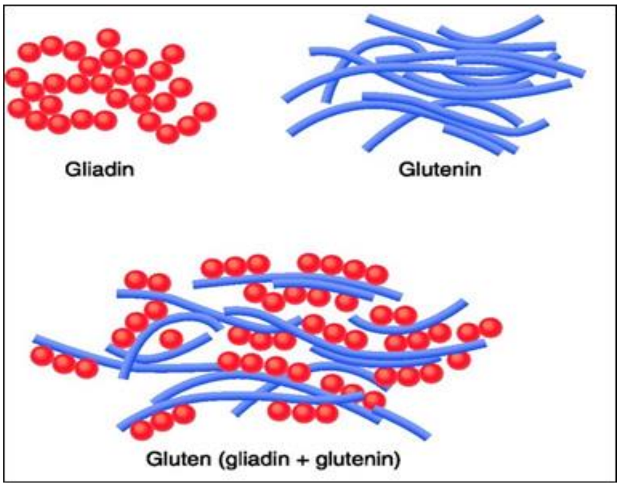


Figure 2: Formation of gluten (Bathula *et al*., 2018).

2. Primary wheat processing

2.1. Cleaning

By removing all undesirable elements, the cleaning of freshly harvested grains generally improves subsequent preservation. The separator-aspirator is made up of three types of slightly inclined sieves, moved back and forth or vibrated and shaken. The wheat is treated by strong suction at the machine's inlet and outlet (Fig. 3).

a. The first sieve (a coarse-perforated reception sieve) allows the wheat to pass through very quickly, removing the largest pieces of waste.

b. The second sieve (main sieve with narrower perforations) allows the wheat to pass through, but removes the slightly larger waste.

c. The third sieve (sand sieve), with pores smaller than the size of the wheat, removes the wheat but allows sand and broken wheat grains to pass through (Boudreau and Ménard, 1992).

Cleaning storage areas is an excellent preventive measure to avoid contamination of healthy batches. Silo walls, conveying equipment and ancillary premises should be regularly cleaned and disinfected.

Figure 3: Cleaning section of wheat (source: https://www.chinagrainmachine.com).

The grain from the silo's storage bin is directed to a de-stoner. This machine separates particles that are similar in size to cereal grains but have different densities. The process is based on the creation of a fluidized bed of grain, through which an upward airflow passes via an inclined sieve. As a result of this airflow, the lighter grains float and slowly move downward along the direction of the sieve's inclination. In contrast, heavier particles, such as stones and other impurities, remain in contact with the sieve. Due to the vibrations of the machine, they are moved in the opposite direction to the grain flow and are discharged separately.

The separation of impurities and dirt is completed on *trieur* station, round shaped impurities or long thin grains are eliminates. Next, the grain is sprayed with water in an intensive dampener. After being moistened with water the grain rests in tempering bins in order to toughen the coating layers and soften the endosperm to make the separation of hulls much easier (Kučerová, 2015).

- **Storage:** Once the grain has been properly cleaned, dried and disinfected, it must be maintained in humidity and temperature conditions compatible with good preservation. The main problem during storage will be to evacuate the heat and steam resulting from the ecosystem's normal metabolism, so it may be necessary to cool the grain if it has been overheated, or to administer an additional insecticide treatment.

Storage techniques :

a. **Storage in a renewed atmosphere:** aeration is ensured either :
   - Periodic transfer from silo to silo (storage tank) (transilage);
   - By a ventilation system installed inside the silo. Air distribution must be homogeneous, silos must be well insulated, and insufficient air must be blown in to cool the entire volume.
   - A ventilation system inside the silo ensures even air distribution; silos must be well insulated and insufficient air must be blown in to cool the entire volume.

b. **Anaerobic storage:** This significantly extends shelf life by blocking the respiratory metabolisms of grains, micro-organisms and insects. There are two technologies for achieving anaerobic conditions:

- ✓ **Confined-atmosphere storage:** This involves storage in a sealed silo whose atmosphere is depleted in O_2 and enriched in CO_2 due to the respiration of the ecosystem;
- ✓ **Storage in a modified atmosphere:** Anaerobiosis is immediately imposed either by vacuum or by saturating the atmosphere with CO_2 or N_2.

2.2. Preparation

At the mill (Reynolds and Braun, 2022):

- **Wheat reception:** After reception at the mill's wheat store, the wheat is stored in bushels (cylindrical containers) for dirty wheat. The different types of wheat arriving at the store are mixed in these bushels to produce well-balanced and high-quality flour.

- **Weighing:** At the outlet of these bushels, the wheat is weighed by means of an automatic scale. The hopper of this scale can contain from 5 to 100 kg of wheat, and is alternately filled and emptied. An automatic counter registers the quantity of dirty wheat destined for milling, enabling us to calculate the extraction rate and the level of impurities by difference with the results recorded on the second scale after cleaning. The weighed wheat is sent to the first cleaning machine (separator-aspirator). The main aim of this machine is to remove 90% of the dust and 70-80% of the other impurities.

- **Cleaning:** see paragraph 2.1.

- **Magnetic:** As it leaves the separator-aspirator, the wheat passes through a device known as a "magnet", either a magnet or an electromagnet. This removes any metal particles that may have passed with the wheat through the separator sieves.

- **Drying:** Virtually mandatory with certain wet harvested grains. In modern industrial practice, drying is carried out in continuous or discontinuous counter-current dryers.

- **Sorting:** The aim is to remove impurities from the wheat that have the same diameter but different lengths, either shorter, such as round grains, vetches and niello, or longer, such as oats and barley. There are two types of sorter: long grain and round grain. The sorter consists of a sheet-metal cylinder whose inner surface is covered with cells whose shape and size vary according to the type of sorting required. It operates at a slight angle and rotates more or less slowly, allowing the grains that remain at the bottom of the cylinder to be moved.

- **Brushing:** The aim is to remove dust from the wheat's brush and furrow, and to remove the outer layers of the husk. This operation is carried out using wheat brushes.

- **Wet cleaning (washing):** Its purpose is to remove all dust and impurities heavier and lighter than wheat grains. It also removes dust in the furrow that has not been removed by the brushing operation. Washing is carried out by a washer-extractor, which is made up of two parts: a washing tank and an extractor column. Wheat is discharged into the washer tank and stirred in the water by an Archimedes screw (used to pump water = rotor that transfers water by helical movement), heavier stones and sand fall to the bottom of the tank, where they are evacuated in the form of sludge. Light waste, on the other hand, floats to the surface, where it is removed as it exits the washer. The wheat passes through the spinner via a beater system, and is lifted to the top of the spinner, where centrifugal force removes much of the surface water that wets the grains.

- **Conditioning:** This operation serves a dual purpose:

  a. To soften the husk and ensure that its moisture content is slightly higher than that of the kernel, so as to facilitate their separation;

b. To bring the floury kernel into a physical state such that it can be reduced to fine flour as quickly as possible.

In the simplest case, the grain is conditioned with normal water for a period strictly fixed at 24 to 36 hours, at a humidity level of 18%: this is cold or passive conditioning. In mills equipped with a conditioner, the grain is subjected to the action of heat (hot condition). In optimum conditioning, the moisture content of the husk is slightly higher than that of the kernel, so it becomes elastic and separates easily into shreds during grinding. The kernel, on the other hand, becomes more fragile, which reduces the energy required for grinding and shortens the milling time. Conditioning can take place in resting bushels or in conditioner-dryers.

2.3. Milling

A. Grinding principles

- Gradually grind the grain so that the husks are broken as little as possible.
- Clean the inside of the husks, trying to keep them as intact as possible;
- Gradually reduce the more or less dressed semolina from the milling process, avoiding as far as possible the husks present on these products.

During the milling process, two types of granulated product are obtained: the "white series" and the "beige series". The white-series product contains more of the kernel than of the husk, while the beige series product contains more of the husk than of the kernel (Fig.4.A).

Wheat milling is defined by the extraction rate (Boudreau and Ménard, 1992):

E.R= Weight of flour extracted / 100g of wheat used

B. Different stages of the milling process

- ✓ **Grinding:** This is the first operation in the milling process, and its purpose is to crush the kernels and fractions containing more husk than kernel. It is carried out by fluted cylinders.
- ✓ **Claking** (transformation into smaller particles) and **converting** (passage of particles through various smooth cylinders to obtain fine products down to flour): These are the two phases in the reduction of products from the grinding process. They are designed to reduce white-series particles. Clackers and converters are smooth rollers.
- ✓ **Sassage:** This is an intermediary operation between grinding and the first phase of reduction of slag products. Its purpose is to purify and classify the products going to the slagging process**.**
- ✓ **Bran curing** (bran is the residue obtained after flour separation): This operation consists of reducing as much as possible the quantity of kernel adhering to the inner face of the husks (using bran brushes).
- ✓ **Blutage** (separation of flour from bran): This is an operation which, after each passage through a cylinder, classifies the ground products into different sizes. What passes through the sieve is the extraction, and what remains on the sieve is the reject. The machine most often used in this operation is the "Plansifter". These are generally made up of two large boxes, each comprising one, two or three vertical compartments containing 10 to 12 superimposed sieves. Each compartment represents a sieving device independent of the neighboring compartment, enabling different products to be sent simultaneously to the same device.
- ✓ **Drying:** A term used in milling vocabulary to designate a special part of the sifting process, which consists of separating the flour mixed with the product (Fig.4.B).

C. Different products of wheat milling

- ✓ **Flour:** this is the main product of the grinding of very fine particles from the kernel and resulting from its reduction.

- **Semolina:** pieces of kernel more or less clothed with an envelope of varying size. There are coarse semolina and fine semolina known as clean or clothed.
- **Finots:** very fine, pure semolina produced by grinding.
- **Grits:** products similar to finots, produced during the reduction of semolina at the top of the slaking and converting lines.
- **Outputs:** finished products other than flour:

  Brans: made up of the husks of the grain and a certain portion of the kernel adhering to the inner phase of these husks; depending on their size, there are coarse brans and fine brans.

  Remoulage: a mixture of more or less finely ground husks and floury kernels. There are: Bis remoulages, which are the largest, and on the diagram they constitute the final refusal of the slab. The white remoulages, which are the finest and richest in flour, represent the output collected at the end of the conversion process.
- **Low flours:** beige-colored, too pitted, corresponding to the flours obtained in small quantities at the end of slaking and conversion. Depending on the desired extraction rate, these flours can be extracted separately (Kučerová, 2015).

(A)

(B)

Figure 4: (A) Milling section and (B) a fully automatic complete flour milling plant (source: https://www.chinagrainmachine.com).

Mill technological process is controlled by **the ash content**. Ash content diagram graphically illustrates the relationship between the flour's ash content and yield. In this respect, it is used the Mohs curve, cumulative curve of ash content of the grain, as it is represented in figure 5 The curve profile depends on the cereal variety, the growing conditions and it is also influenced by how the cleaning – conditioning process is run and implicitly by the equipment in the cleaning section.

The red curve shows a shift to the right, which can be interpreted as an increase of extraction at the same ash content, with lower ash content, if the rate of extraction is kept as reference. Given the quality indicators of grain weight and of the grain itself, there were suggested various formulas to calculate a so-called 'Grinding quality' of the wheat.

The best way to assess the grinding quality of a batch of wheat still remains a small scale grinding or a laboratory milling for that batch of wheat.

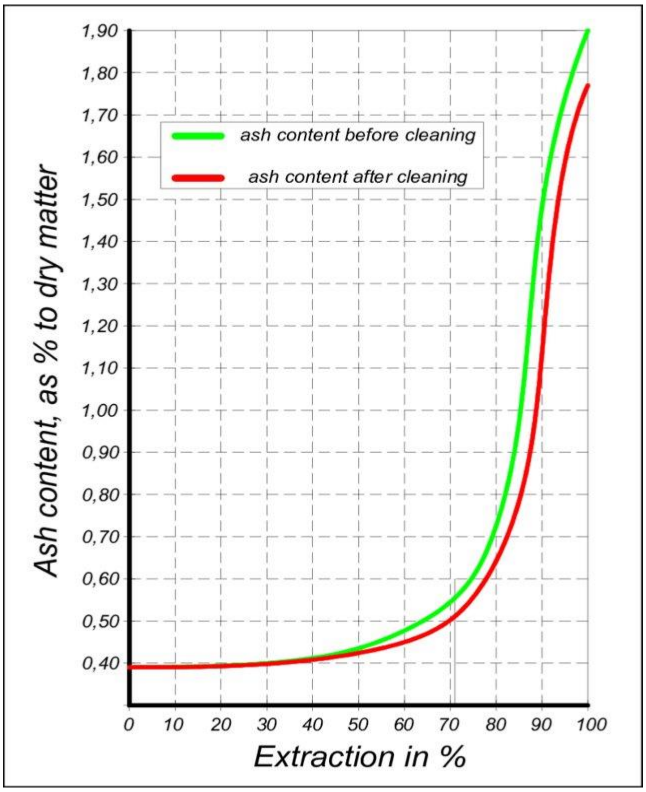


Figure 5: Mohs curve of variation of ash content depending on the extraction percentage (Tanase, 2013).

3. Linear wheat processing

3.1. Bread-making

3.1.1. Definition of bread: It is the product resulting from cooking the dough obtained by kneading a mixture of wheat flour for bread-making, drinking water, cooking salt and a fermentation agent. The mixture may include certain authorized adjuvants or additives.

3.1.2. Bread-making principles: Pour For the usual preparation of bakery dough, a suitable mixture of flour is mixed with water and salt and kneaded for 10 to 20 minutes. Yeast is then added to the dough. Fermentation lasts 2 to 3 hours, releasing CO_2 as the dough swells, forming pockets of gas trapped between the thin gluten membranes. The optimum duration of dough maturation (kneading and fermentation) to obtain good rheological properties depends on the strength of the flours (kneading tolerance is greater with strong flours). The dough is then cut, shaped and incised, left to swell again for around an hour, and baked for 20 to 40 minutes in an oven at 235 to 260°C. Baking coagulates certain proteins, fixing the spongy structure of the crumb. Bread preparation takes 4 to 8 hours (Stanley, 2015).

3.1.3. Bread ingredients

- **Flour:** the most important component of dough, generally it is from wheat.
  Baking quality of wheat flour is expressed as:
  - **Flour strength** is determined by the amount and quality of protein (gluten) and physical properties of doughs (the dough’s ability to retain leavening gases generated during rising)
  - **Gassing power of the flour** is determined by the ability to generate sufficient amounts of leavening gas (CO2). The correct course of fermentation is ensured by a sufficient activity of yeast
  - **Sugar-forming ability of flour** is given by the sufficiency of fermentable sugars, which are already present in the flour (pre-existing sugars), sugars generated in the dough by the action of amylases on starch as well as sugars added as recipe ingredients.

- **Water:** Water hydrates the flour, swells the starch grains and helps soften and elongate the gluten, giving the dough its plastic properties, allowing it to develop and be shaped.
- **Salt (NaCl):** Firstly, it improves the dough's plastic qualities (firmness and tenacity), and also enables the addition of water to be raised slightly; secondly, it acts as a regulator, slowing down fermentation slightly; thirdly, it enhances crust coloring during baking; and fourthly, it improves the bread's flavor.
- **Yeast:** The precise industrial baker's yeast is *Saccharomyces cerevisae*. It provokes fermentation and transforms sugars into alcohol and CO_2.

  Fresh compressed yeast is the most widely used for economic reasons. It may contain up to 74 % of water. It is intended for preparation of leavened doughs, for controlled rising, frozen semi-products and there are also yeast specially adapted for loosening sour bread doughs.

  Dried yeast is produced in the form of granules or beads. It has a longer shelf life; at room temperature it survives even 24 months (it is filled under nitrogen atmosphere or in vacuum). Moisture ranges from 7 to 9 %. Before use, it needs to be activated in water (Stanley, 2015).

3.1.4. Improvers, additives and their roles

The properties of flour can often be modified and sometimes improved, whether in terms of color, diastatic power (e.g. the degradation of starch into sugar) or the plastic properties of doughs, by means of treatment or the addition of biological or chemical products.

- **Bean flour:** A maximum of 2% is added to bread flour. It improves gas production and sometimes crust coloring through a very slight activation of amylolysis and a very slight addition of fermentable sugars.
- **Malted products:** Can be added to flour up to 0.3%. Their role is to correct hypodiastatic flours and re-establish an enzymatic balance suitable for bread fermentation. The main active ingredient in malt is amylase, a hydrolyzing diastase that transforms starch into sugars (maltose and dextrin). This dual

contribution amplifies the fermentative activity of the dough and increases the quantity of residual sugars essential for the coloring of the crust during baking.

Note: Malt is a germinated cereal from barley, which is cooked to release its aromas**.**

- **Gluten powder:** can be used for :
    a. Improving the flour's strength and helping to balance its plastic properties (in this case it is used at a rate of 1.5 to 1.5%);
    b. Reinforce the physical properties of doughs in the manufacture of specialty breads (1 to 2.5%).
- **Ascorbic acid:** The maximum dose used is 30 g/quintal of flour (quintal (q) = 100 kilograms). Ascorbic acid, which is naturally an antioxidant, becomes an active oxidizing agent when incorporated into the dough.
    a. It enhances the physical properties of doughs, increasing their tenacity and reducing their viscosity, as well as improving their shelf life;
    b. The resulting oxidation causes only a very slight whitening of the crumb, and has no effect on the bread's taste. It does, however, accelerate dough ripening;
    c. During long-term fermentation, it can also enhance dough holding and gas retention, by protecting the physical properties of the dough against the activity of proteolytic ferments;
    d. It also influences crust coloring, which it helps to slow down (used to correct hyperdiastatic flours).
- **Lecithin** (a large group of lipids = phosphatidylcholine): Can be used in doses of 100 to 300 g/quintal of flour. It is an emulsifying agent (promotes mixing between immiscible liquids such as water and oil) whose action tends to lubricate the dough and improve its extensibility (stretching capacity). It also acts as an antioxidant, slightly slowing dough whitening and altering bread taste.
- **Sugars:** Sucrose is an ingredient in Viennese products, facilitating fermentation and enhancing finesse (lightness) (Stanley, 2015).

- **Baking soda (bicarbonate of soda):** Sodium bicarbonate decomposes into sodium carbonate, carbon dioxide and water.

$$NaHCO_3 \rightarrow Na_2CO_3 + CO_2 + H_2O$$

The advantage of using baking soda is that it affects the color of baked products and their softness.

3.1.5. Dough production

a. Kneading

It ensures that the raw materials are thoroughly mixed and the dough made. There are two types of kneading: manual kneading (with arms), and mechanical kneading (with mechanical kneading machines). Whatever the method, kneading comprises 2 distinct phases:

- **Milling:** The aim is to mix all the components until all traces of water and flour have disappeared, resulting in roughly homogeneous dough.
- **Cutting, stretching and blowing:** During this phase, the glutinous network is formed, giving the dough its plastic properties (elasticity, tenacity and extensibility).

Two methods of kneading:

Periodic process (discontinuous): raw materials are dosed into the mixing vessels (troughs) and are mixed and kneaded in a kneader mixer to obtain a homogeneous dough, which matures in the trough or is tumbled out into the hopper and from the hopper to a maturing belt.

Continuous process: raw materials are fed into the back part of a screw kneading machine where they are mixed and kneaded to obtain a homogeneous dough, which falls out on the underside of the front part of the kneader (Kučerová, 2015).

The dough is prepared in kneading machine or mixers. Kneading machines may be of low intensity (kneading time 15 to 20 min) and medium intensity (kneading time 6 – 10 min). Mixers have a high intensity of kneading up to 2 minutes. Kneaded dough has a temperature between 27 and 29 °C, with titratable acidity of 70 to 90 mmol/kg.

b. Hydration

Flour hydration results from its combination with water during kneading. Knowing the quantity of water and flour used, we can calculate the flour's absorption percentage. Example: 50 kg of flour requires 30 l of water. So C.A = 30/50 × 100 = 60%.

c. Dough fermentation

It is an alcoholic fermentation generated by the action of ferments on the sugars present in the dough, which transform them into alcohol and CO_2. The ferments used can be provided by:

- Natural sourdough, which is an artisanal culture of wild ferments (*Saccharomyces micor*);
- Organic baker's yeast: *Saccharomyces cerevisiae* is an industrial culture of suitable ferments collected from brewer's yeast.

Sugars come from:

a. Pre-existing sugars (glucose and especially sucrose);

b. Sugars generated by amylolysis and degradation of a fraction of starch by cereal amylases during fermentation.

Only glucose and levulose are directly assimilated by yeast. Enzymes present in the dough transform sucrose into glucose and levulose, thanks to saccharase. Maltase transforms maltose into 2 glucoses. At the end of the fermentation cycle, another enzyme, zymase converts levulose and glucose into alcohol and CO_2.

There are 2 fermentation stages:

Pointing: is the period of fermentation between the end of kneading and the weighing of the dough.

Priming: this is the fermentation period from turning to baking (Stanley, 2015).

Numerous factors inside and outside the dough modify its fermentative abilities and physical properties.

a. External factors come from the environment, and include ambient temperature and humidity.

b. The internal factors are: the baking value of the flour used its extraction rate, its granulation and the state of the leaven.

D. Moulding

- **Weighing:** After proofing, the dough is divided into a number of dough pieces equal to the number of loaves to be made in the batch. To obtain loaves of a given weight, the dough pieces are weighed. In all cases, the dough must be divided using a dough piece cutter, not by hand.
- **Turning:** This is the operation during which the baker gives the dough, which has been weighed, the shape required for the type of bread to be made. This shape must be regular and correct.
- **Priming:** Once the dough has been shaped, it is placed on a layer or sheet to undergo priming fermentation.

Bread moulding machines are:

Rounding machines: Dough is homogenized; the rounder closes the cut surfaces and gives each cut piece a uniformly spherical shape (conical rounder of dough loaves, belt-type rounder for bread dough) of the loaf.

Molder machines: shape of rolls (forming the dough into a cylindrical shape). Shaped bread pieces are stored in baskets either manually or using the mechanical equipment of the proofer (Kučerová, 2015).

E. Cooking

- **Cutting:** This affects both the bread's appearance and its development. The first consequence of incising (horizontal cuts) the dough pieces before placing them in the oven is to artificially create zones that allow the CO_2 to push through, thus contributing to their maximum development.

- **Fogging:** Today's ovens are equipped with fogging devices (electric ovens have a special "fogging" button which causes water to be introduced into the oven, falling on very hot pieces of metal and vaporizing to form steam). The role of steam is manifold:

  a. Allows dough pieces to wait for a larger volume;

  b. Favors the development of "jets" resulting from blade strokes;

  c. Has a major influence on crust color and appearance: condensation, which transforms starch into complex products of the caramel family, gives the crust a golden-yellow color with a slightly glossy, glazed appearance.

- **Baking:** During baking, the fermented dough is transformed into loaves. During the first phase, fermentation inside the dough continues until the internal heat, reaching a temperature of between 45 and 50°C, destroys the ferments and stops them in their tracks. Under the influence of heat, all the gases expand (increase in volume) and under their pressure the dough swells, the internal alveoli increase in volume and their walls become thinner. The rise in temperature then acts between 60 and 70°C on the gluten, which coagulates, and on the starch, which is transformed into starch. The result is a gradual and rapid loss of plasticity in the dough-sheet walls, and a definitive loss of bread structure. During the 2nd phase, the action of the heat causes only the surface of the dough in contact with it to dry out, forming the crust and thus the final baking of the bread. Baking time varies according to the weight and shape of the dough pieces: 45 to 50 minutes for large breads and 12 to 13 minutes for small breads (Fig.6) (Stanley, 2015).

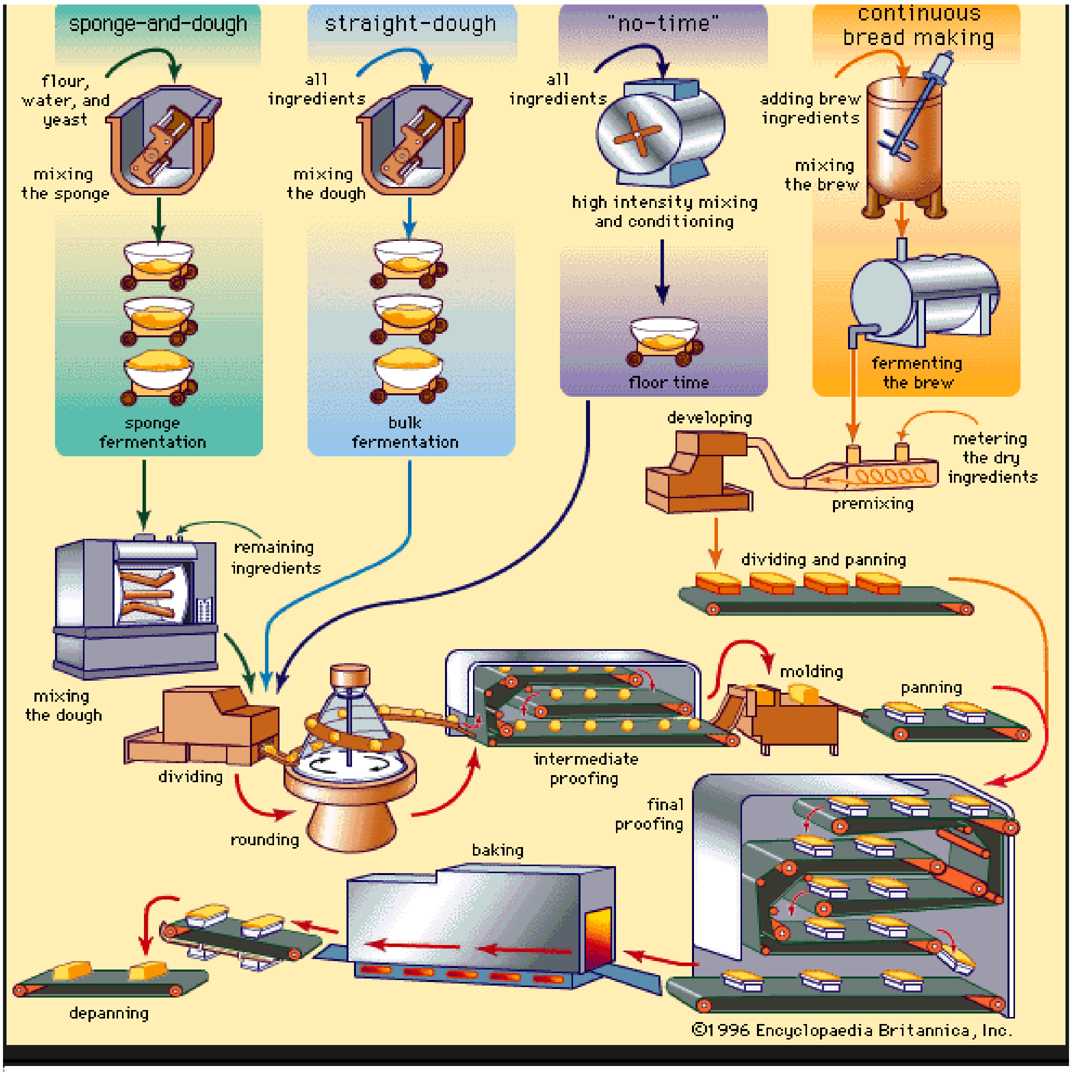


Figure 6: Essential steps in four commercial bread-making processes (source: https://ihmnotessite.com).

3.2. Pasta production

3.2.1. Definition: Pasta is the product obtained by the unfermented and unsalted kneading of durum wheat semolina and water in an average proportion of 34 parts semolina to 6 to 10 parts water.

Pasta is widely recognized as a versatile food that is easy to prepare and offers an excellent nutritional profile. It aligns well with current dietary recommendations, being low in fat, very low in cholesterol and sodium, and containing a balanced proportion of complex carbohydrates and proteins. On average, pasta consists of about 12% protein, 72 to 76% carbohydrates, 12 to 13% water, 0.5 to 0.7% fats, along with essential minerals (iron, calcium, phosphorus) and vitamins B1 and B2.

3.2.2. Classification

Pasta can be divided into two categories, depending on the type of machine used:

- **Pressed pasta:** Two products types:
  1. Solid pasta prepared by extrusion (spaghetti, vermicelli, soup pasta, star pasta);
  2. Hollow products prepared by extrusion (macaroni, shells).
- **Laminated pasta:** long noodles, butterfly noodles.

Pasta is also divided according to shape into:

- **Long-cut:** spaghetti, bucatiny, macaroni.
- **Medium-cut:** cut macaroni, smooth and grooved rigatoni, large and medium-sized pasta in various shapes (square-shaped, seashell-shaped, and many more).
- **Short-cut:** small-sized pasta in various shapes (seashell-shaped, letter-shaped, ring-shaped, flat-shaped, rice-shaped, and many more).

Above groups are further divided into:

- **Dry pasta** that is dried after being shaped to reduce the moisture content to less than 13 percent by weight;
- **Fresh undried pasta** that is slightly dried after being shaped to have the total moisture content at least 20 and not more than 30 percent by weight;
- **Stuffed pasta;**
- **Frozen pasta;**
- **Pasta packed under either vacuum or inert atmosphere** (Delcour and Hoseney, 2010).

3.2.3. Raw materials used

- **Semolina:** it must have a homogeneous granulometry (grain size) to enable even hydration during kneading.
- **Water:** must be potable.
- **Additives:** They can be divided into 4 groups
  - Substances increasing nutritive value (eggs, milk, soy, gluten);
  - Flavouring substances (fruit and vegetable juices, pastes, aromatizing substances);
  - Improvers (antioxidants preventing degradation of carotenoids in the flour).

3.2.4. Manufacturing process

A. Preparing the semolina: The semolina used is sieved in a plansifter to remove any impurities and foreign matter it may contain (bag straws, bits of string, pieces of label and sometimes insect larvae).

B. Different stages in the manufacturing process: several operations are grouped into 2 technologies (Kill and Turnbull, 2000):

- **Kneading technology**

1. **Kneading:** Consiste involves mixing the water and semolina thoroughly. The amount of water added is 280 l/t of semolina, so that the final water content of the dough is around 33% of the wet matter, taking into account the initial moisture content of the semolina, which averages 14%. Kneading is carried out in 2 stages:

   a. Preparation of the ingredients in a pre-mixing vat of variable length and diameter, depending on the press in question;
   b. Kneading, this takes place either in a vacuum tank to prevent air bubbles from forming in the dough.

2. **Shaping:** The purpose of shaping is to bring the dough into the desired commercial form by passing it under pressure through the dies of a mold. Depending on the type of dough to be manufactured, 3 different operations are required:
    - **Pressing:** the dough obtained after kneading is taken up by an endless screw whose dual function is to allow the products to advance while compressing them so as to cause their extrusion through a mold located at the head of the screw (Fig.7).
    - **Wire drawing:** dies are placed at the head of the press, and depending on the shape of these dies and the speed at which the pasta is cut as it leaves the press; the desired format of finished products (spaghetti and vermicelli) is obtained.
    - **Laminating:** the pasta is laminated by passing between 2 rollers to be cut into the desired shape (long noodle).

➢ **Drying technology**

The aim is to reduce the water content of the dough to ensure good preservation. Drying must not alter the shape or appearance of the dough, and must render it insensitive to normal external influences. It must achieve a state of equilibrium between the main constituents (starch, gluten, etc.) so that the dough, while retaining a certain degree of elasticity, can resist breaking. Traditionally, doughs are dried in hot air at fairly high humidity and relatively low temperature; this avoids protein denaturation and starch gelatinization, which are the consequences of too rapid evaporation.

Current drying technology comprises 3 stages:

1) Pre-drying

The main purpose of this stage is to remove surface water, so that the doughs remain individualized during the drying process. The water is removed from the dough by a stream of air that has been preheated by passing through heat exchangers in which hot water circulates.

2) Intermediate drying

It is considered as a rest period for the dough to be dried. Its purpose is to re-establish the moisture balance that has been disrupted by the intense heating undergone during pre-drying. It is carried out using thermo-fans (heating coil + fan) which inject hot air inside the dryers.

3) Final drying

This consists in gradually bringing the dough to its equilibrium moisture content (11.5 to 12.5%). Drying time varies according to format, all things being equal.

Example: For dry and humid temperatures of 55 and 50°C respectively, the drying time is 5 hours for medium curly vermicelli and 14.5 hours for spaghetti.

- **Storage and packing**

Pasta is stored in bins in areas with relative humidity not exceeding 75 %. It is packed in plastic bags, which can be stored for 1 to 2 years. Undried pasta must be stored at temperatures not exceeding 5°C, while pasta packed under vacuum or inert atmosphere must be stored at temperatures not exceeding 10 °C. Fresh undried pasta is transported in isothermic packages or isothermic vehicles.

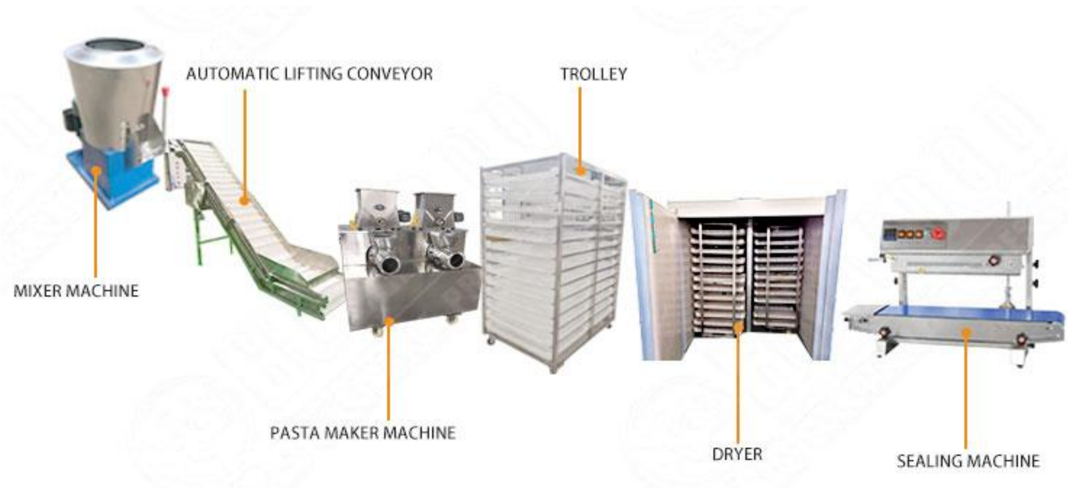


Figure 7: Macaroni production line (source: https://loyalfoodmachine.com).

After manufacturing, quality and sensory of pasta are evaluated:

- **Appearance and shape** must match the commercial type;
- **The point of fracture** of pressed pasta must be vitreous, that of rolled pasta may be even slightly mealy;
- **The color** is bright, even, in various shades of yellow;
- **Aroma and taste are pleasant** and correspond to the raw materials, additives or flavorings used (Kučerová, 2015).

3.3. Couscous production

3.3.1. Definition of couscous

Couscous is a product made from durum wheat semolina (*Triticum durum*), which has been agglomerated by adding drinking water and subjected to physical treatments such as cooking and drying (Codex Alimentarius, 1995).

3.3.2. Composition of couscous

The Codex Alimentarius (a joint program of the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) consisting of a collection of standards, codes of practice and recommendations relating to food production and processing, with the aim of ensuring food safety...) (Codex standard 202-1995) states that the moisture content of couscous must not exceed 13.5%, with a maximum ash content of 1.1%. The biochemical composition of industrial couscous is similar to that of the durum wheat semolina used as raw material (Tab. 2) (Codex Alimentarius, 1995).

3.3.3. Making couscous

Couscous is made from a mixture of coarse and fine semolina. It can also be made from "coarse-medium" semolina (codex standard 202-1995). During the couscous manufacturing process, the semolina must be hydrated with salted water containing 4-5 g NaCl/l.

The steps involved in making commercial couscous are identical to those for traditional couscous. Traditionally, North African women make their couscous by hand, but since 1953, couscous production has been industrialized.

Table 2: Protein and starch contents (g/100 g dry matter) of durum wheat semolina, coproducts generated during the manufacturing process and dry couscous grains (Abecassis *et al.*, 2012).

Composition	Durum Wheat Semolina	Wet Recyclates	Cooked and Dry Recyclates	Dried Couscous Grains
Water content	13–15	30–35	8–11	10–13
Gelatinized starch content	84–88	84–88	84–88	84–88
Gelatinized starch content	4–6	15–25	80–90	80–90
Total protein content	11–15	11–15	11–15	11–15
Soluble protein content	11–13	9–11	2–4	2–4
Total pentosan content	1–2	1–2	1–2	1–2
Soluble pentosan content	0–0.1	0–0.1	0–0.1	0–0.1

a. Artisanal method

Artisanal couscous is the product of the agglomeration of semolina (coarse and fine) under the effect of hydration and rolling. The raw material first undergoes classification to separate coarse particles (Ø > 500µm) and fine particles (Ø ≤ 500 µm) from the semolina. Then the coarse semolina is hydrated with salted water and rolled by hand several times, each time adding a quantity of the fine semolina and sometimes durum wheat flour (Ø ≤ 280 µm). In some regions, the coarse semolina is previously treated with steam before going through the hydration stage. The semolina agglomerate is then sieved to obtain wet couscous, which is subsequently steam precooked, crumbed, graded and air- and sun-dried (Fig.8).

Homemade couscous is traditionally prepared using coarse semolina. The semolina is classified into two fractions using a sieve with a 0.5 mm mesh opening (known as “ghorbel chaâr”): coarse semolina (referred to as “fetla”) and fine semolina (referred to as “dkak”) (Figure 11). This classification step improves the semolina’s agglomeration yield by promoting the formation of granules rather than sticky dough clumps (Hammami *et al.,* 2022).

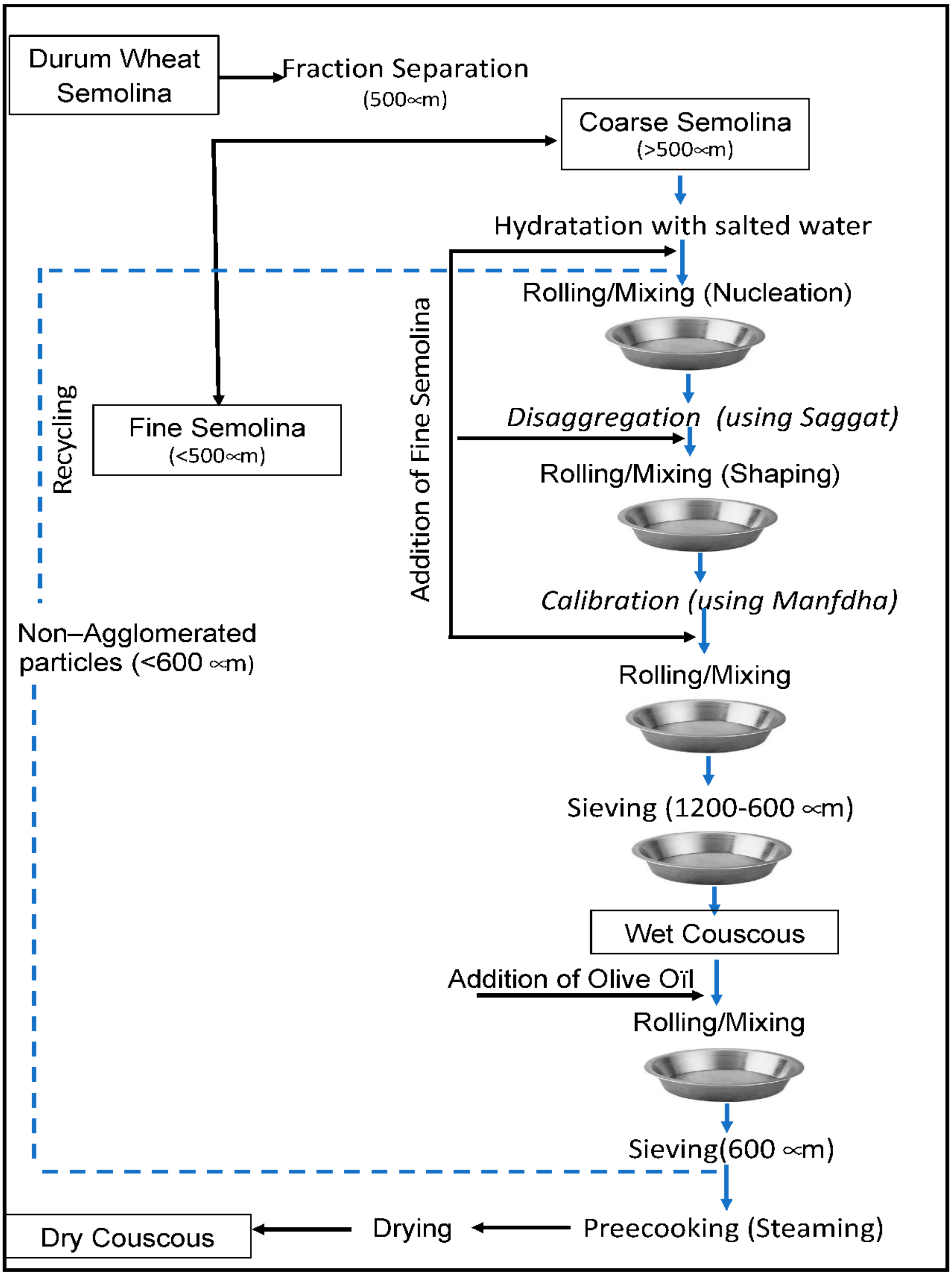


Figure 8: Traditional couscous making diagram (Hammami *et al.*, 2022).

b. Industrial method

Industrial couscous is prepared from a mixture of one-third coarse semolina (630 to 800 µm) and two-thirds fine semolina (250 to 630 µm).

Industrial couscous production begins with continuous hydration of semolina and salt (around 30 liters of water for 100 kilograms of semolina), followed by rolling and steaming (180°C for 8 minutes). After cooking, the wet couscous is cured (in two stages, the first at 65°C for 120 minutes and the second at 55°C for 270 minutes), cooled and sieved using a plansichter.

Industrial couscous, known as fast couscous because it is considered pre-cooked, is obtained by mechanical rolling, pre-cooking and drying. It is manufactured on separate lines from pasta. Industrially, couscous can be produced continuously at 500 kilograms per hour.

At the industrial level, agglomeration involving wetting and mixing operations can be achieved using two main types of equipment:

(i) Simultaneous wetting and mixing systems: These systems typically employ a horizontal mechanical mixer equipped with dual rotating shafts. Water is directly applied onto the semolina during the mixing process, replicating traditional manual methods while enhancing process efficiency. The high rotational speed of the mixing shafts ensures uniform water distribution across the semolina particles and facilitates the initiation of agglomeration through improved particle interaction.

(ii) Sequential hydration and mixing systems: In this configuration, semolina particles undergo individual hydration through water spraying prior to mixing. This is performed in a high-shear environment that promotes particle separation and the uniform coating of each particle with water. The hydrated particles are then immediately transferred to a high-intensity double-shaft horizontal mixer, where vigorous mechanical mixing promotes effective agglomerate formation.

Two types of equipment are available for carrying out the rolling and sifting operations.

(i) **The plansichters** consist of a series of superimposed flat vibrating sieves with openings of decreasing diameter;

(ii) **The rotary drum rollers** consist of a succession of sections within a slightly inclined cylindrical drum.

Wet couscous grains are cooked by steam injection in a continuous tunnel cooker. The drying stage of couscous grains is conducted on pods circulating in a hot air drying tunnel, with controlled flow rate, temperature and relative humidity of air. Dry couscous grains are graded according to size criteria depending on the target diameter. Products collected at the exit of the cooler are deposited at the top of a column of vibrating sieves, with decreasing mesh. The products are separated into three categories.

- Too fine particles with a diameter below the target diameter mainly come from breakage or erosion mechanisms of couscous grains during the drying stage. The flow of fine particles can represent 5–7% of the throughput of dry couscous grains;
- Several dry couscous grains in the diameter target can be produced: fine (0.63 < diameter < 1.25 mm), medium (1.25 < diameter < 1.85 mm) or coarse (1.85 < diameter< 2 mm) couscous grains;
- Too large particles with a size greater than the target diameter are usually clusters of several couscous grains that have stuck together during the cooking or drying stages. These particles are sent to a roller mill for size reduction and then sifted again.

Discarded products are reintroduced at the agglomeration stage (Abecassis *et al*., 2012).

Figure 9 shows the agglomeration of semolina during rolling.

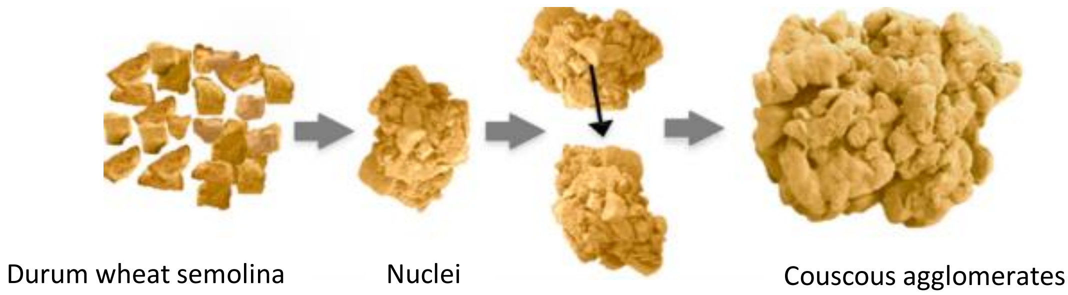


Figure 9: Durum wheat semolina agglomeration mechanism (Ruiz *et al*., 2014).

The nuclei are the result of the first association of semolina particles. The structure of the nuclei is stable thanks to the capillary bridges generated by the force of friction between the semolina particles. Many nuclei can be combined by the coalescence mechanism, giving agglomerates with hydration between 0.40 and 0.55 (g water/g dry matter).

Artisanal couscous grains are irregular particles with a more or less spherical shape and a rough surface. Industrial couscous has more regular particles, with a more homogeneous, spherical shape and a smooth surface (Fig.10).

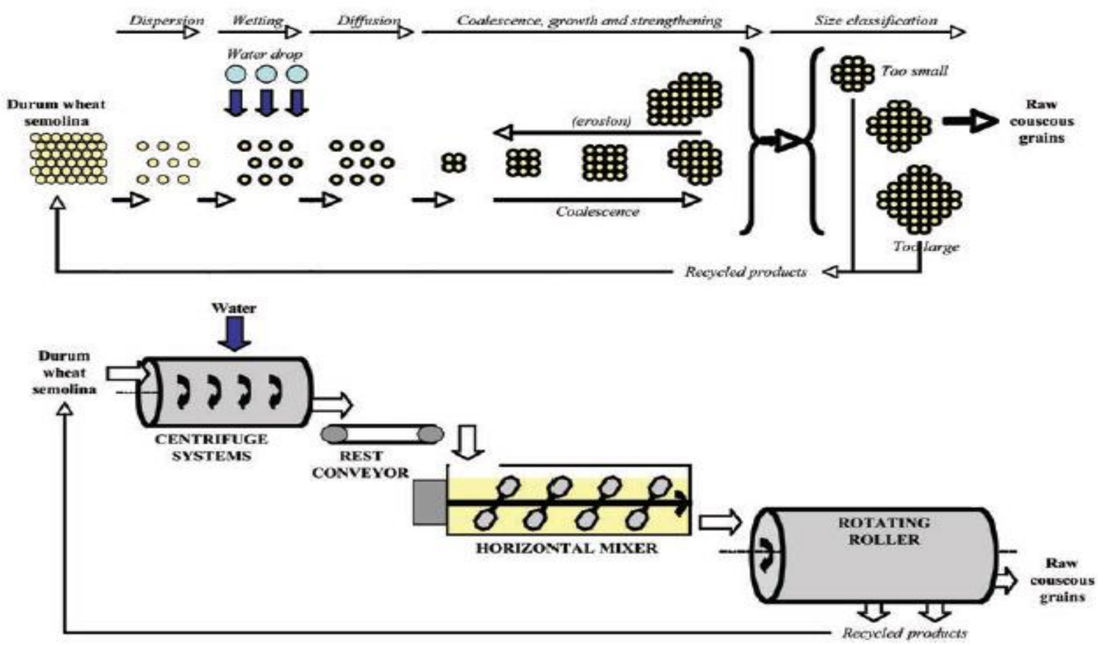


Figure 10: Schematic representation of the centrifugal wetting system equipment used to agglomerate semolina (Abecassis *et al*., 2012).

III. METHODS FOR ASSESSING WHEAT QUALITY

1. Assessment of soft wheat

1.1. Baking value

The baking value of wheat represents its aptitude for flour yield. This flour yield is characterized by the extraction rate.

$$\text{Extraction rate} = \frac{\text{Flour weight}}{\text{Milled grain weight}} \times 100$$

A. Bakery or bread-making value

- **Baking strength = Chopin alveograph test**

It is the essential test for flour technological quality. It consists in measuring the resistance and extensibility of a dough formed with flour and salted water (25 g/l). The result is called the baking strength, denoted by W (Fig. 11).

The procedure defines the formation of dough of flour and salt water in a small laboratory mixer. Kneading time and water content are always constant. After kneading, the dough is rolled and cut into circular test tubes. After a rest period of 20 min, the test tube is swollen, and a recorder is used to plot the deformation of the dough until it bursts (Boudreau and Ménard, 1992).

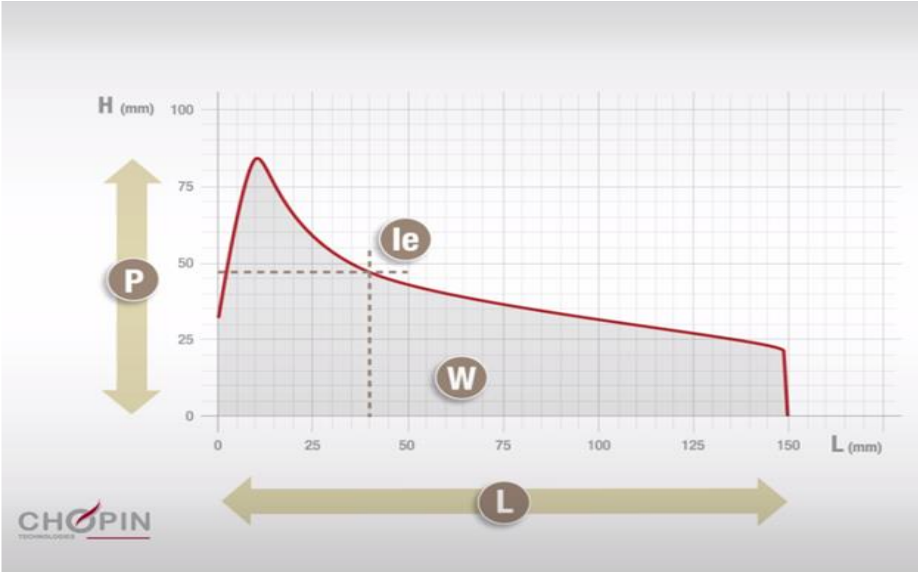


Figure 11: Alveographic curve (source: https://www.iaom.org).

P: Toughness (ability to resist deformation)

L: Extensibility (maximum volume of air the bubble can contain)

P/L: Ratio of toughness and extensibility curves

Ie: Index of elasticity, le = P200/P (P200: pressure at 4 cm from the start of the curve)

W: Baking strength of the dough (area under the curve) or energy value.

The W or area of the diagram correlates fairly well with the amount of gluten.

Example:

- Cookie flours range from 100 to 150.
- Artisanal bakery flours cover the 150 - 220 range.
- Industrial bakery flours should be between 220 and 280.

➢ **Fermentation properties**

- **Hagberg method = falling number test= fermentation test.**

This test determines flour’s capacity to break down starch into sugars that can be assimilated by yeast (Fig. 12).

If this capacity is high, the fermentation rate is too fast. Breads will then have a multitude of defects (underdeveloped, sticky crumb, red crust, poorly thrown blade strokes).

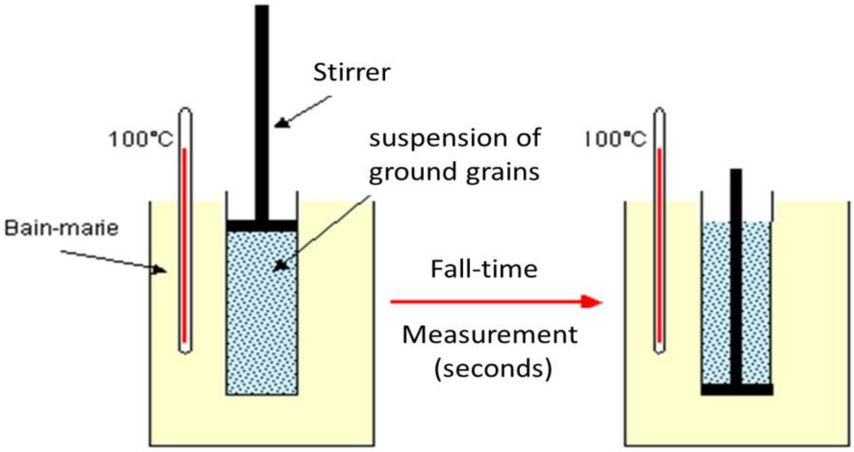


Figure 12: Principle of the Hagberg Method.

1.2. Baking test

Small experimental batches of product are made and baked to test for baking quality (Slade *et al*., 2020).

The volume yield of the loaves is initially determined for each individual loaf and then an average value of the three loaves formed. In addition to the volume yield, the fermentation tolerance based on the bread shape of the third loaf (80 minutes of fermentation time) is evaluated. Due to the crumb of the loaves, the crumb appearance and the crumb texture can also be evaluated.

Baking behaviour	Very good	Good	Satisfactory	Not satisfactory
Volume yield (ml baked goods volume/100 g flour)	above 630	600 – 630	570 – 599	below 570

2. Assessment of durum wheat

2.1. Semolina value : the ability of durum wheat to be processed into semolina:

- **Mitadinage rate**

  Mitadinage is a physiological accident of the albumen which, from hard and vitreous (resembling glass) becomes more opaque and floury (examination of less than 600 grains by Infra-Red spectroscopy).

- **Thousand kernel weight (TKW):**

It is determined by counting whole kernels, and the results are expressed in dry kernel weight.

$$P = [1000 \times P'/ N] \times [100 / 100 - H]$$

P : actual weight of 1000 grains. N : number of 30 g whole grains. P' : weight of test sample (30 g). H : humidity.

- **Speckling**

Speckling of durum wheat, characterized by brown to black spots on the ripe wheat kernel, contributes to the poor appearance of pasta (Delcour and Hoseney, 2010).

2.2. Pasta value

The ease with which semolina can be transformed into pasta (machinability) plus culinary quality: there's a test called the European test, which determines the non-stickiness and machinability of a dough obtained from a mixture of flour, water, yeast, salt and sucrose (Kill and Turnbull, 2000).

2.3. Couscous value

- **Cold and hot swelling indices**

It corresponds to the water absorption capacity of the pasta during cooking. Typical values are 280-320 ml water/100 g couscous at 25°C, and 380-410 ml water/100 g couscous at 100°C.

- **Couscous mass index**

It is linked to the agglomeration of couscous grains after rehydration, and corresponds to the percentage of couscous that forms large agglomerates (>3 mm). This index can be assessed by sieving (Ruiz *et al*., 2014).

IV. CORN INDUSTRIES

1. Overview

Corn classification and composition

Family: *Poaceae*

Sub-family: *Panicoideae*

Species : *Zea mays* (Varieties are subspecies)

The chemical composition and nutritional value of corn kernels give them a good position among cereals in the food category (Fig. 13).

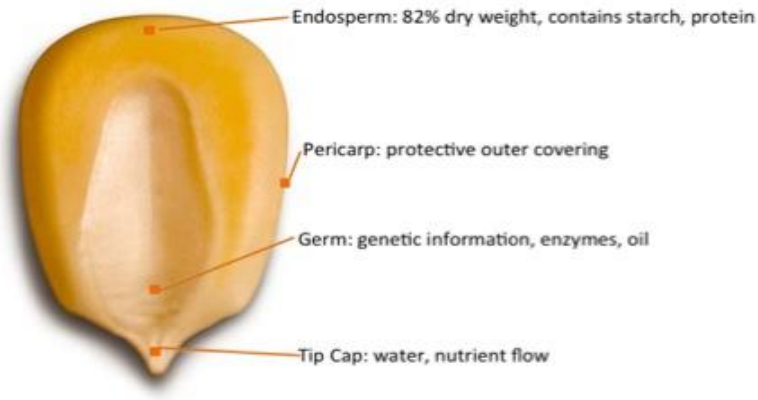


Figure 13: Chemical composition of the main parts of corn kernels (Akbar, 2020).

Maize is demanding in terms of soil, water and heat (below 10°C, seeds will not germinate). Maize likes deep, cool, fairly light, well-drained soils that are fertile and rich in organic matter.

The color of the maize kernel can be quite variable. It may be solid or variegated and can be white, yellow, red, blue, dark brown, or purple. Yellow is the most common color, followed by white. The hull, or pericarp, makes up about 536% of the kernel and is coated with a layer of wax. The germ is relatively large, composing 10-14% of the kernel. The remaining part of the kernel is endosperm.

Maize protein occurs in the endosperm as discrete protein bodies and as a matrix protein. The protein bodies are composed mainly of a prolamin called 'zein'. The endosperm contains about 5% albumins plus globulins, about 44% zein, and about 28% glutelins. The remaining protein is mainly a zein fraction (about 17%) cross-linked by disulfide bonds that is soluble in alcoholic media containing mercaptoethanol (a disulfide-bond-breaking agent) or a similar solvent (Akbar, 2020).

2. Corn processing

Processed maize is used in a wide range of food products. Starch production is the industrial process used to extract starch from plant products, including corn kernels.

Corn kernels are transformed into valuable foodstuffs and industrial products using two processes: dry milling and wet milling (Fig.14).

- **Dry milling**

By-products are quite numerous, their variety depending to a large extent on particle size. They are classified as hominy (large kernel fragments), grits (medium fragments), semolina and corn flour, obtained using 3.5 to 60 gauge sieves. Their chemical composition has been well established, and their many uses include brewing, the manufacture of appetite suppressants and breakfast cereals, and many others.

- **Wet milling**

In developed countries such as the USA, most corn is processed by wet milling to provide starch and other valuable by-products, such as corn gluten, flour and animal feed.

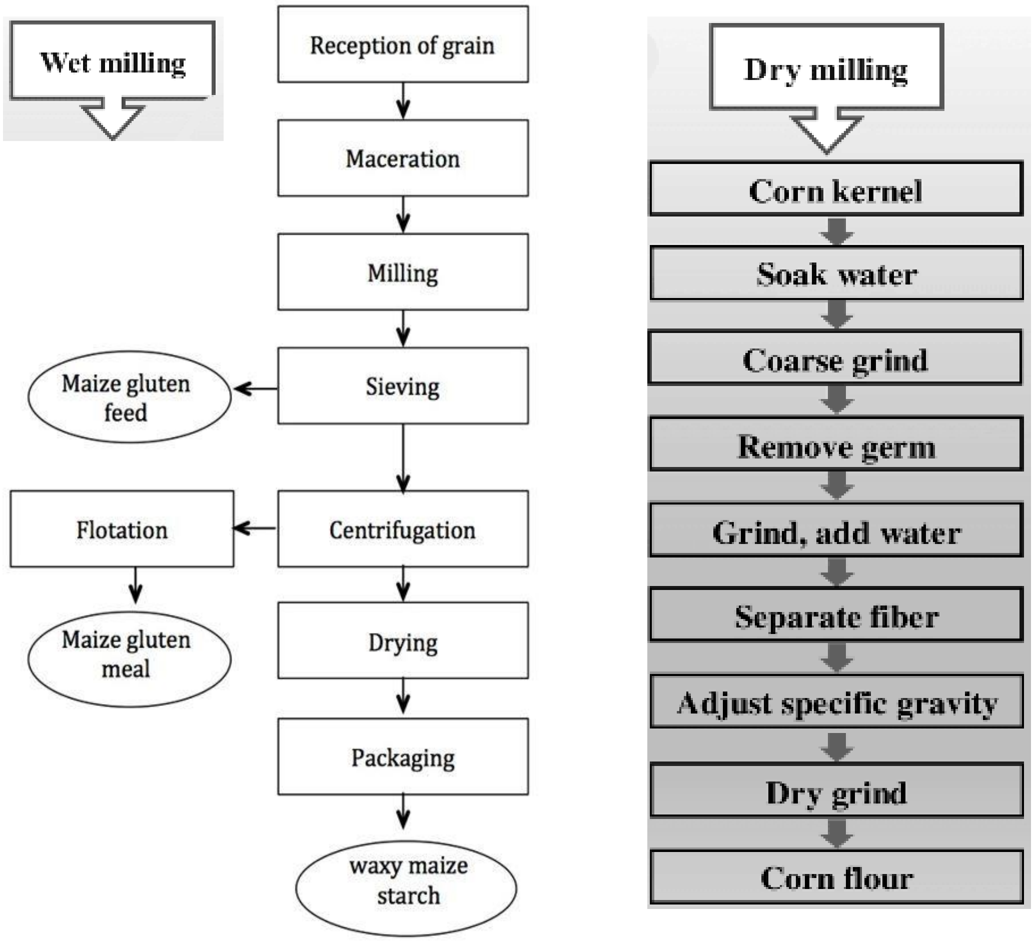


Figure 14: Wet and dry milling of corn (Zhang *et al.*, 2021).

V. RICE

1. Overview

Rice belongs to the *Poaceae* family.

The species most often grown in more or less flooded fields called rice paddies are:

- *Oryza sativa* (commonly known as "Asian rice")
- *Oryza glaberrima* (commonly known as "West African rice")

The rice grain consists of a protective husk (or glumella) and a fruit (caryopsis).

Once harvested, rice can be marketed at various stages of processing:

- Paddy rice (rice on the ground in the rice field) is raw, dehusked rice that has retained its husk after threshing.

- Cargo rice, or brown rice, is "husked rice" from which only the rice husk has been removed, but from which the bran and germ are still present.
- White rice, or milled rice, or wholly milled rice, from which the pericarp and germ have been removed.
- Parboiled rice, often referred to as uncollectible rice, is white rice or cargo rice, heat-treated before marketing to prevent the grains from sticking together.

The usual classification of rice according to grain size is as follows:

- Long-grain rice, whose grains must measure at least 7 to 8 mm and are quite fine. When cooked, the grains swell little, their shape is preserved and they hardly clump together.
- Medium-grain rice, whose grains are wider than long-grain rice (the ratio between length and width oscillates between 2 and 3) and reach a length of between 5 and 6 millimeters. Most often, this type of rice is slightly stickier than long-grain rice.
- Short-grain, round-grain or oval-grain rice. The grains are generally 4 to 5 mm long and 2.5 mm wide. They often stick together (Delcour and Hoseney, 2010).

2. Primary processing-Milling

- **Threshing:** This involves separating the seeds from the straw. Care must be taken to avoid damaging the seeds.
- **Winnowing:** to remove immature or damaged grains and impurities (insects, weed seeds, plant debris, stones, etc.).
- **Drying (natural after threshing or artificial):** After harvesting, the rice grain is still damp. It must be dried to ensure that it keeps well. Overly prolonged exposure to heat causes the grains to split.

3. Secondary processing

- **Hulling (from paddy to cargo = whole-grain rice):** this stage begins with cleaning, and then the paddy grains pass over two rubber rollers rotating in opposite directions to remove the glumella (outer husk of the grain).

- **Bleaching (white rice):** Cargo rice is whitened by abrasion (removal of bran and germ). Abrasion is carried out using machines equipped with rotating stones, which grate the peripheral part of the grain. After three or four passes, the rice becomes permanently white.
- **Parboiling (parboiled rice):** is a hydro-thermal process lasting 24 hours. The color of the grain turns yellow as the steam causes the pigments to migrate from the husk to the inside of the grain. The product is then dried, shelled, processed and preserved. This transformation leads to the gelatinization of the starch, which gives the product elasticity and texture, possibly enriches it with minerals through migration from the pericarp during steaming, and makes it less susceptible to attack by parasites because it is harder (Fig. 15).

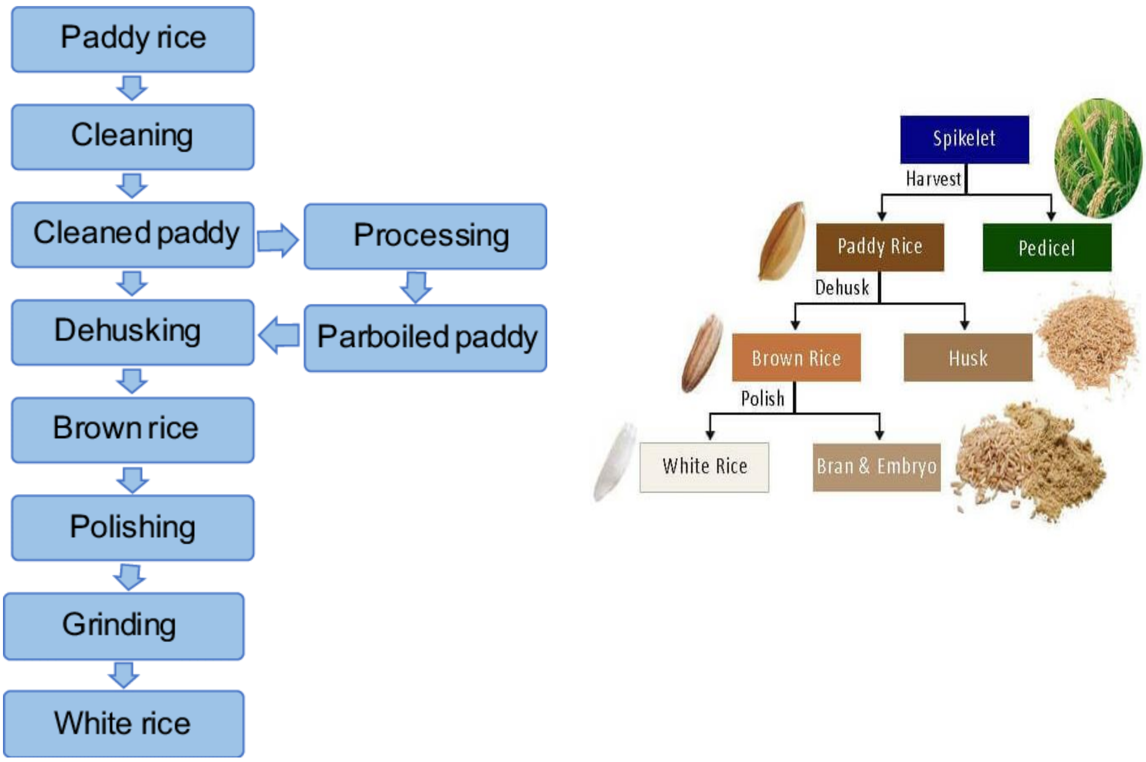


Figure 15: Rice processing (Papageorgiou and Skendi, 2018).

The milling of brown rice is essentially the removal of the bran by pearling to produce white rice. In the pearler or milling machine (Fig. 16), some rice breakage inevitably occurs. In some cultivars of rice, the bran is more difficult to remove than in others. In such cases, a small amount of water can be added to soften the bran layers before milling. Dry calcium carbonate (about 3.3 g/kg) is added to the brown rice. It is an abrasive that helps in removing the bran.

In a typical pearler, the brown rice enters through a flow-regulating valve and is then conveyed by a screw to the pearling chamber, where the mixing roller causes the grains to rub against each other, abrading off the bran. Most of the bran is removed by the grain rubbing on other grains, although a small amount is also removed by the grain rubbing on the steel screen surrounding the chamber. At the discharge end of the pearling chamber is a plate that is held in place by a weight. The position of the weight varies the pressure on the plate and thus the back pressure on the rice in the pearling chamber. The degree of milling can be controlled by varying the pressure and thereby changing the average residence time in the chamber (Delcour and Hoseney, 2010).

Generally, the miller visually determines the proper setting and the degree of milling and tries to achieve a reasonable throughput, with a uniform degree of milling, while keeping breakage to an absolute minimum. The head rice (unbroken milled kernels) brings a much higher price than the brokens, which are generally sold to be used as adjunct in brewing or as raw material for industrial rice starch isolation. The miller therefore takes every possible action to increase head rice yields and minimize the quantities of brokens (Papageorgiou and Skendi, 2018).

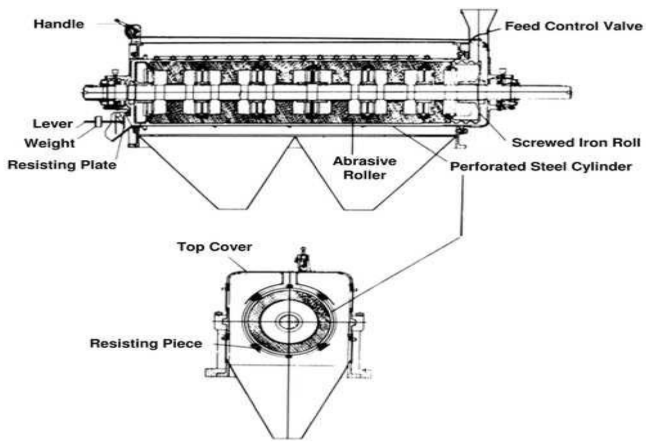


Figure 16: Illustration of a pearler that can be used to mill rice or to pearl barley (Delcour and Hoseney, 2010).

4. Culinary quality of cooked rice

- **Swelling power:** an increase in the volume of rice after cooking. For the same quantity of uncooked rice and for the same preparation, rice that takes up more volume on the plate is more appreciated than rice that takes up less volume.
- **Texture:** Rice presents different aspects after cooking. But the aspect most sought-after by the consumers surveyed is the non-sticky appearance of the grains. The texture of rice after cooking depends on the paddy's processing method. The water content of the cargo rice is one of the factors that influence texture. If the cargo rice is not completely dry when cooked, it has a pasty appearance, making it undesirable for consumers. The pasty appearance of rice also results from the fact that the starch is not completely gelatinized during parboiling.
- **Taste:** It is an organoleptic factor for assessing rice quality. The taste criterion is an important socio-cultural factor that depends on the consumer's eating habits. To be desired by the consumer, rice must have a good taste.

- **Cooking time:** This criterion is used by consumers to refer to the time it takes raw rice to cook completely. Consumers look for rice that cooks quickly, as longer cooking times increase energy costs (Papageorgiou and Skendi, 2018).

Part 2

FRUITS AND VEGETABLES TECHNOLOGY

PART 2: FRUITS AND VEGETABLES TECHNOLOGY

INTRODUCTION

- **Review of the usefulness of preservation techniques**

To make food available throughout the year, humans have developed methods to extend the storage life of products to preserve them. The rotting process can be postponed by:

- Adding preservatives;
- Optimizing storage conditions;
- Applying modern techniques.

Most fruits and vegetables are edible for a very short time as they are seasonal, unless they are promptly and properly preserved. Insects can cause a lot of damage, not only by eating the products, but also by passing on microorganisms. The aim of food preservation treatments is to preserve edibility, taste and nutritional properties by preventing the development of microorganisms (bacteria, fungi, etc.) that can in some cases lead to food poisoning (Diane *et al.,* 2004).

- **Different factors in fruits and vegetables spoilage**

Fruits and vegetables spoilage, or rotting, is any modification that causes them to lose their desired quality and make them unfit for consumption (Fig.17):

- Physical deterioration is caused, for example, by dehydration.
- Physiological ageing occurs as soon as the biological cycle is interrupted by harvesting.
- Deterioration caused by insects or rodents.
- Chemical and enzymatic deterioration: Chemical and enzymatic deterioration occurs mainly when vegetables and fruit are damaged by falling or breaking. This releases enzymes that trigger chemical reactions.
- Microbial spoilage.

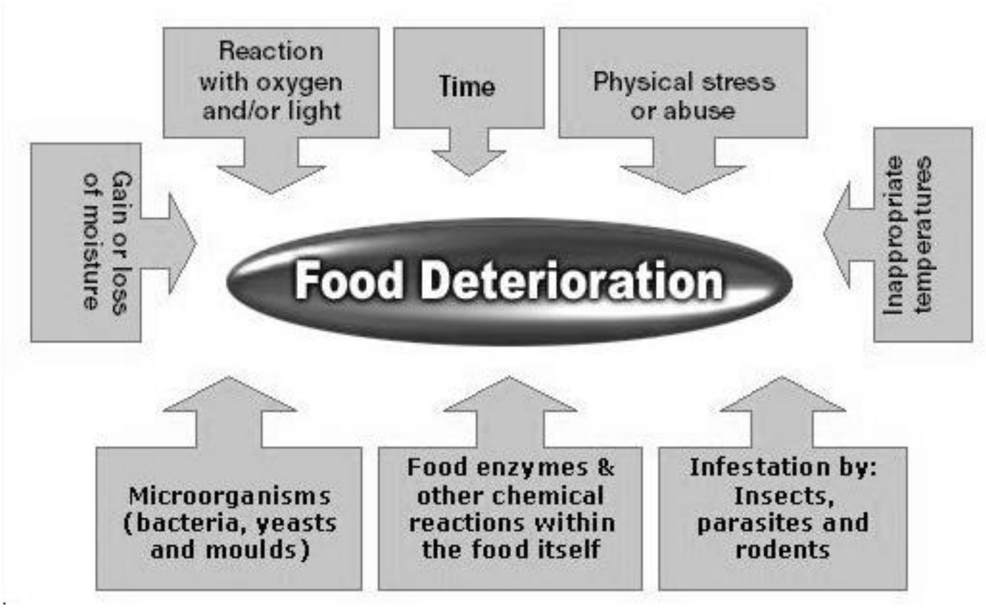


Figure 17: Different factors of food deterioration (Source: https://wiki.ubc.ca/Course).

Spoilage of fruits occurs due to various physical and chemical damages, enzymatic digestion, but most significantly due to microbial activity. The spoilage of fruits due to microbial activity initiates when spoilage microorganisms invade the fruit. The microbial communities grow and multiply on the fruit bringing undesirable changes to original state of the fruit. All organisms need nutrients for their metabolic activities and microorganisms are not an exception. Spoilage microorganisms also need nutrients to grow and they generally get the necessary nutrients from the host organism. Fruits are highly concentrated in nutrients necessary for spoilage microorganism's growth, and that makes them nearly ideal host for the survival and growth of many types of microorganisms. Those microorganisms may come from various sources during the (Tab. 3) (Zhao *et al,* 2022).

Several factors can influence the spoilage of fruit and vegetables:

- **Water activity:** free water is essential for microorganisms to multiply. This requirement varies with the species (0< Aw < 1). Fruits and vegetables have an aw of 0.97 to 0.99. They therefore provide a favorable environment for microbial development.
- **Osmotic pressure:** When the osmotic pressure of a food is low, the volume of bioavailable water is high, and microorganisms are therefore able to grow.

- **Nutrient conditions:** Each microorganism has its own nutrient requirements.
- **pH:** an acid pH favors the development of yeasts and molds; a neutral or alkaline pH favors bacteria during rotting.
- **Physical structure:** cutting and chopping fruits and vegetables increases the surface area for contamination.
- **Relative humidity:** High relative humidity, even at low temperatures, is conducive to microbial growth.
- **Temperature:** It has a major influence on the growth of micro-organisms (psychrophilic, mesophilic, thermophilic, etc.).

Table 3: Possible sources of pathogenic microorganisms on fruits and vegetables (Zhao *et al.*, 2022).

Pre-harvest	Post-harvest
• Faeces • Soil • Irrigation water • Green and inadequately composted manure • Air (dust) • Wild and domestic animals Human handling	• Faeces • Human handling • Harvesting equipment • Transport containers • Wild and domestic animals • Air (dust) • Wash and rinse water • Processing equipment • Ice Transport vehicles

Fruits and vegetables are rich on carbohydrates, proteins and lipids and these are as a major source of energy for their metabolic activities (Tab. 4).

Table 4: Compositional features of fruits and vegetables (Slavin and Lloyd, 2012).

	g/100 g edible matter
Water	61.0–89.1
Protein	0.5–1.1
Fat	Trace – 4.4
Sugar	4.4–34.8
Starch	Trace – 3.0
Dietary Fibre	2.0–14.8
Energy, kcal	90–646
Micronutrient	Vitamin C, K, Mg, Carotenoids
Toxic constituent.	Cyanogenetic glycosides in seeds

- **Ripeness**

There is a distinction between maturity and ripeness of a fruit:

- Maturity is the condition when the fruit is ready to eat or if picked will become ready to eat after further ripening.
- Ripeness is that optimum condition when colour, flavour and texture have developed to their peak.

Ripening corresponds to a sequence of biochemical and physiological changes leading to the state of ripeness and conferring on fruit and vegetables their organoleptic characteristics in terms of taste, aroma, color and texture, which make them marketable and edible.

Ripeness may or may not change after harvest (depending on the species). The signs of fruit and vegetable ripeness are as follows:

- Color: this determines the consumer's first positive or negative impression. For example, as fruit ripens the color changes from green to red.
- Firmness: Loss of firmness is the result of chemical synthesis or activation during ripening.
- Odor: When fruit and vegetables ripen, specific volatile compounds are produced. These are the source of their odor.
- Flavor: The flavor of a fruit depends in particular on its sugar content. During ripening, this sugar content increases as the fruit's starch is broken down (Diane *et al.,* 2004).

I. PRELIMINARY TREATMENTS FOR CANNING, FREEZING, DEHYDRATION

1. Washing, Sorting, Blanching

- **Washing:** Fruits and vegetables must be thoroughly cleaned to remove any remaining dirt or insecticides. Some produce, such as plums and grapes, are immersed for 5 to 15 seconds in a solution containing hot, almost boiling soda (NaOH; 10-20 g soda per liter of water), which makes the skin rough and speeds up the drying process. After this treatment, rinse the fruit thoroughly with cold water. The disadvantages of soda are that it can discolor vegetables and corrode metal utensils.

- **Sorting:** To obtain a uniform product, fruit and vegetables are sorted according to size, shape, weight or color. It is particularly important to sort produce for drying or heating according to size, as this determines the time required for these operations.
- **Peeling:** Many types of fruit and vegetables need to be peeled before they can be preserved. Peeling is easily done with a stainless steel knife; this detail is very important, as it will prevent discoloration of the flesh. Tomatoes and peaches, whose skin adheres firmly to the flesh, are best immersed in hot water for 1½ to 3 minutes. The softened skin can then be easily removed.
- **Cutting:** It's important to cut produce because you need roughly equal pieces for cooking, drying and packaging.
- **Blanching:** or precooking, fruit and vegetables are immersed in water at 90-95°. They can also be exposed to steam, which softens the produce and eliminates enzymes (Verma and Joshi, 2000).

II. HEAT PRESERVATION

1. Appertization

Appertization, also known as "canning", is a heat treatment involving the sterilization of perishable foodstuffs in containers that are hermetically sealed against liquids, gases and micro-organisms (metal cans, jars). Foods heated to a temperature of 110 to 120°C are freed from any micro-organisms or enzymes likely to spoil them.

2. Packaging

Packaging is the wrapping that represents a product offered for sale. There are three types of packaging: Primary packaging covers the product. It is presented as it is to the end consumer who buys the item in question. Secondary packaging groups and packages the same products in a single carton or other material. It protects the primary packaging, but its presence is optional. Tertiary packaging is the container for many goods. They are transported to sales outlets or dispatched within the company.

3. Filling, Juicing

Filling is used to fill cans or jars with the product to be sterilized. Juicing is where the covering liquid (juice or sauce) is added to the can. This liquid facilitates heat transfer during sterilization, and allows salt, sugar, spices and additives to be incorporated evenly.

4. Sealing

Sealing or crimping is a mechanical operation used to assemble the lid onto the body of a can. The purpose of crimping is to close the container after filling, thus ensuring that the can remains airtight to prevent subsequent recontamination, particularly microbiological recontamination.

5. Pre-heating

Plants are soaked in a bath of boiling, salted water for a few minutes to perform a number of technological functions: modify the structure of the plant tissue, eliminate the air contained in the plants and reduce the microbial load. Blanching in a boiling water or steam bath puts an end to certain enzymatic reactions in the product, and allows better retention of color and taste after processing (Fitz and Kuipers, 2003).

III. STERILIZATION

1. Reminders

Sterilization in the food industry consists of a selected heat treatment, applied to kill microorganisms and their spores at a temperature > 100°C, so as to prevent spoilage.

Conventional thermal sterilization is explained by the United States Food and Drug Administration (FDA, Silver Spring, MD, USA) as any process using heat either alone or in combination with technologies that can lead to the inactivation of microorganisms including mesophiles and thermophiles to ensure that spoilage and food poisoning is eradicated. The conventional method for evaluating the efficiency of thermal processing is dependent on the thermal value/lethality value or sterilization value F0 (F-value), which is then defined as the time (minutes) required to eliminate a known population of the resistant bacterial population in a given food under specified conditions (Tab. 5) (Soni and Brightwell, 2022).

Table 5: Sterilization value or F0 for vegetables and fruits (Soni and Brightwell, 2022).

Composition of the Product	F_0- Approximate Sterilization Value/Range (min.)
Asparagus	$F_{121} = 3$
Carrot puree	$F_{121} = 4.9$
Celery pure in a stew	$F_{121} = 8$
Green beans in brine	$F_{121} = 6$
Canned gudeg (jackfruit and spices) in coconut milk	$F_{121} = 28$
Onions in calcium brine	$F_{121} = 6$
Peach low acid canned food	$F_{93} = 3$

2. Sterilization of acidic products

Acidic products with a pH below 4.5 are subjected to a more moderate heat treatment, often at a temperature below 100°C (pasteurization). Moreover, in certain cases, when the product is suitable, the pH can be lowered below 4.5, for example by adding organic acids, vinegar, etc... These are acidified products with a pH below 4.5, in which case it is also possible to stabilize the product by heat treatment below 100°C (pasteurization).

This pasteurization heat treatment, combined with a pH below 4.5 (homogeneous throughout the product) and airtight packaging, can guarantee the biological stability of products at room temperature.

3. Sterilization of non-acidic products

Products with a pH of 4.5 or above are processed at temperatures above 100°C (sterilization between 105°C and 140°C) to ensure sufficient destruction of *Clostridium botulinum* spores and biological stability at room temperature. This is the case for most appertized products. The set pH limit of 4.5 or above corresponds to the growth limit of

Clostridium botulinum (the reference pathogenic spore-forming germ), and also of most other spore-forming germs.

Certain toxins, as well as other harmful substances such as histamine, are thermostable and therefore not destroyed by sterilization: this is the case, for example, with the emetogenic toxin of *Bacillus cereus*, staphylococcal enterotoxins and phycotoxins. Professionals must therefore be vigilant, doing everything in their power to prevent the initial contamination of products (in particular, through the selection of suppliers) and to avoid encouraging the production of these toxins during the manufacturing stages (Verma and Joshi, 2000).

4. Sterilization devices

Galvanized steel sterilizers: they are self-contained, have a large capacity, and are generally placed on a gas stove whose burner, depending on the model, can develop 9000KW. Their locking system prevents the jars from colliding with each other.

Electric sterilizers: a manual or digital thermostat enables precise temperature adjustment. They are ideal for domestic use.

Autoclaves: These are thick-walled, hermetically sealed metal pressure vessels that use high-temperature steam to sterilize.

Figure 18 shows a sterilization unit.

5. Sterilization defects

During sterilization, certain temperatures must be reached. If these temperatures are not reached, certain micro-organisms and spores can survive in the cans, making them unsafe for consumption.

If the time-temperature combination is not carried out correctly, the food will lose its organoleptic properties.

When packaging food, it's important to bear in mind that some containers require an empty space at the top. Failure to do so may result in a leaky seal or breakage of the container (Fitz and Kuipers, 2003).

Figure 18: Sterilizer for canned fruits and vegetables (Source: https://genyang.en.com).

6. Use of appertized products

The purpose of heat treatment is to ensure the product's biological stability at room temperature.

Appertized fruit and vegetables are widely consumed everyday products. Their level of consumption has been relatively stable for several years.

The foodstuff to be appertized is extremely fresh. Because of storage conditions and shelf-life, it often provides a better vitamin intake than fresh market produce when stored for long periods: we know that it only takes 24 hours' storage for asparagus to lose 40% of its vitamin C, spinach 30% and green beans 20%.

In the case of fruit and vegetables, industrial appertization, which takes place within a very short time after harvesting, means that the food has better vitamin content than raw produce, which has already lost much of its freshness and vitamins before cooking.

7. Microwave treatments

The principle behind microwave technology is to sterilize packaged foods by immersing them in pressurized hot water, while simultaneously heating them with microwaves at a frequency of 915 MHz, a frequency that enables the waves to penetrate the food more deeply than with the 2450 MHz frequency used in domestic ovens. The combination eliminates pathogenic bacteria and spoilage microorganisms in just 5 to 8 minutes, producing healthy food of better quality than conventionally produced, ready-to-eat food.

Microwave-Assisted Thermal Sterilization (MATS) technology employs a combination of both thermal (convection) and microwave energy (conduction) to sterilize food in polymeric packages to ensure microbial inactivation that is considered equivalent to thermal sterilization; however, with reduced loss of sensitive nutrients unlike thermal sterilization In this process, the food (in polymeric packages) is kept submerged in hot water at 121 °C and treated using microwaves (915 MHz) under pressurized hot water to achieve the desired F0 to eliminate bacterial contaminants . This technology is relatively new and is mostly used for ready-to-eat food products that have vegetable and fruit portions. The benefit of MATS over thermal sterilization is its reduced processing time, which can thereby reduce nutrient loss. A few studies that have reported success in achieving a more than 6 log reduction in bacterial spore formers in fruit or vegetable matrices are listed in Table 6 (Soni and Brightwell, 2022).

Table 6: Effect of microwave-assisted/induced sterilization with heat on bacterial inactivation in fruits/vegetable products (Soni and Brightwell, 2022).

Parameters/Settings	Product	Bacterial Inactivation Potential
Coaxially-induced microwave sterilization at 915 MHz, microwave power of 22 kW, where the food package was moved back and forth at a speed of 130 cm/min under circulating water at 121 °C for a total processing time of 68.3 min	Mashed potato	1–2 log CFU/g and >6 log CFU/g for *Geobacillus stearothermophilus* and *Clostridium sporogenes* spores, respectively
Continuous-flow microwave heating operating at 915 MHz, microwave power of 60 kW, preheated by pumping hot water at 130 °C and recirculating it for approximately 30 min ($F_0 = 5.13$)	Sweet potato puree	4.85×10^6 log CFU/mL reduction in *Bacillus subtilis* spores

IV. CANNING TECHNOLOGY

1. Canning of vegetables

- **Selection of vegetables**
  - Vegetables must be absolutely fresh;
  - Vegetables must be free of dirt;
  - They must be free from stains, insect damage or mechanical damage.
- **Sorting, Washing, Peeling, Cutting and Blanching:** these steps are explained in section § I. Preliminary treatments.
- **Cooling:** After blanching, the vegetables are immersed in cold water for better handling and to keep them in good condition.
- **Filling:** Before filling, the cans are washed in hot water and sterilized, but in developing countries, they are subjected to a steam jet to eliminate dust and foreign matter. After filling, the cans are covered with brine; this process is called "brining".
- **Evacuation:** The process of removing air from the cans is known as exhausting. The main advantages are as follows:

Tinplate corrosion and pinhole formation during storage are avoided;

- Minimizes discoloration by preventing oxidation;
- Reduces chemical reaction between container and contents;
- Prevents the development of excessive pressure and tension during sterilization.

The canister is heated until the water temperature reaches 82 to 100°C, and the center of the canister is about 79°C. Exhaust time varies from 6 to 1 minute, depending on the nature of the product. For glass jars and bottles, vacuum-sealing machines are generally used.

- **Sealing:** Immediately after exhaustion, cans are hermetically sealed using a can sealer. In the case of glass jars, a rubber ring must be placed between the mouth of the jar and the lid, so that it can be sealed airtight. During sealing, the temperature must not fall below 74°C.

- **Processing:** Heating food for preservation is known as processing, but in canning technology, processing means heating or cooling canned food to inactivate bacteria. Many bacterial spores can be killed by high or very low temperatures. Such radical processing does, however, affect food quality. Processing time and temperature must be sufficient to eliminate all bacterial growth. In addition, overcooking should be avoided, as it alters the flavor and appearance of the product. Almost all fruit and vegetables can be processed satisfactorily at a temperature of 100°C, i.e. in boiling water. In addition, they do not develop in the heavy sugar syrup normally used for fruit canning. Vegetables which are not acidic by nature, have a hard texture and are close to the ground, which can infect them with spore-carrying organisms, are processed at higher temperatures of 115 to 121°C.
- **Cooling:** After processing. Cans are rapidly cooled to around 39°C to stop the curing process. Cooling is carried out using the following methods:
  - Immerse hot cans in tanks containing cold water;
  - Introduce cold water into the pressure cooker, particularly in the case of vegetables;
  - Spray cans with jets of cold water;
  - Expose cans to the air.

If canned products are not cooled immediately after processing, peas become pulpy and taste cooked, and many vegetables develop a flat sour taste (become acidic).

- **Storage:** Once the cans have been labelled, they should be packed in sturdy wooden crates or corrugated cardboard boxes and stored in a cool, dry place. The outer surface of the cans must be dry, as even small traces of moisture can cause rusting. Storage of cans at high temperatures should be avoided, as this shortens the shelf life of the product and often leads to the formation of hydrogen swelling. The shelf life of canned products varies according to the type of raw materials used. Canned beans, spinach, peas, etc. can be kept for around two years, while canned carrots, beet, etc. can only be kept for a relatively short period (Fig.19) (Hathi *et al.*, 2023).

2. Canning of fruits

- **Selection of Fruits**

- The fruits must be ripe but firm, and uniformly mature. Overripe fruits should be discarded as they are infected by microorganisms and result in a poor-quality product.
- The tomatoes must be firm, fully ripe, and deep red.
- Unripe and immature fruits should be rejected because they generally shrivel and toughened on canning.

- **Sorting and Grading**

Raw material should be sorted based on maturity and ripeness. Fruit should be graded according to size and colour to obtain uniform quality of canned product. Grading can be done by hand or by machines. Screw type and roller type grader are generally used.

Fruits like berries, cherries, grape and plum are graded whole, while peach, pear, apricot, mango, pineapple, etc., are generally graded after cutting into pieces.

- Washing, peeling, cutting, blanching, and filling processes are the same for vegetables.
- **Syruping**

A solution of sugar in water is called syrup. Generally the fruits are covered with sugar syrup. Cans are filled with hot (79°–82°C) sugar syrup, leaving a headspace of 0.3 to 0.5cm. Syrup of 10° to 55° Brix (per cent sucrose) is generally used. We can prepare sugar syrup of 20° Brix by dissolving 250 g sugar in one-liter water and of 50o Brix by dissolving one kg of sugar in one litre water. Sometimes citric acid and ascorbic acid are also mixed with the syrup to improve flavour and nutritional value, respectively. The purpose of adding syrup to fruits is (1) to improve taste, (2) to fill up the interspaces in can, and (3) to facilitate further processing.

- Exhausting, Sealing, Processing, and Cooling are decribed in canning vegetables methods.

- **Testing for Defects**

  Before the canned products are marketed, we should test them for any defect. Leaky cans should be removed from the lot.

- **Storage, labelling and packing**

  Before storage, the cans should be completely dry, small traces of moisture are likely to induce rusting. They should be stored in a cool and dry place. Before dispatch, the cans are labelled and packed either in wooden or cardboard boxes, and are ready for marketing. The cans may be stored for 1 to 2 years depending upon the type of raw materials used and the shelf life of the product (Fig. 19) (Ganvit *et al.*, 2023).

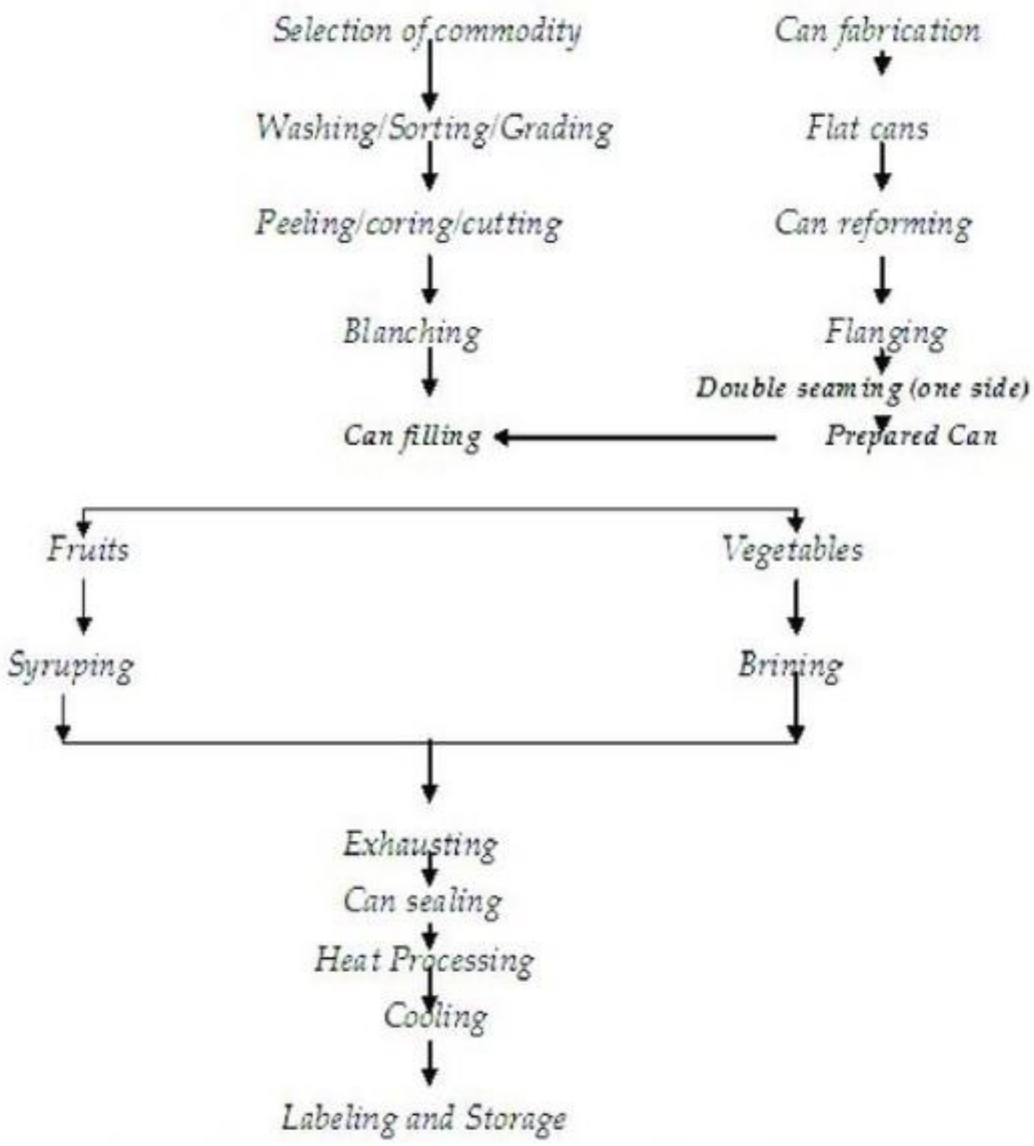


Figure 19: Flow-sheet for canning of fruits and vegetables (Ganvit *et al.*, 2023).

Figure 20 shows the canned cucumber production line.

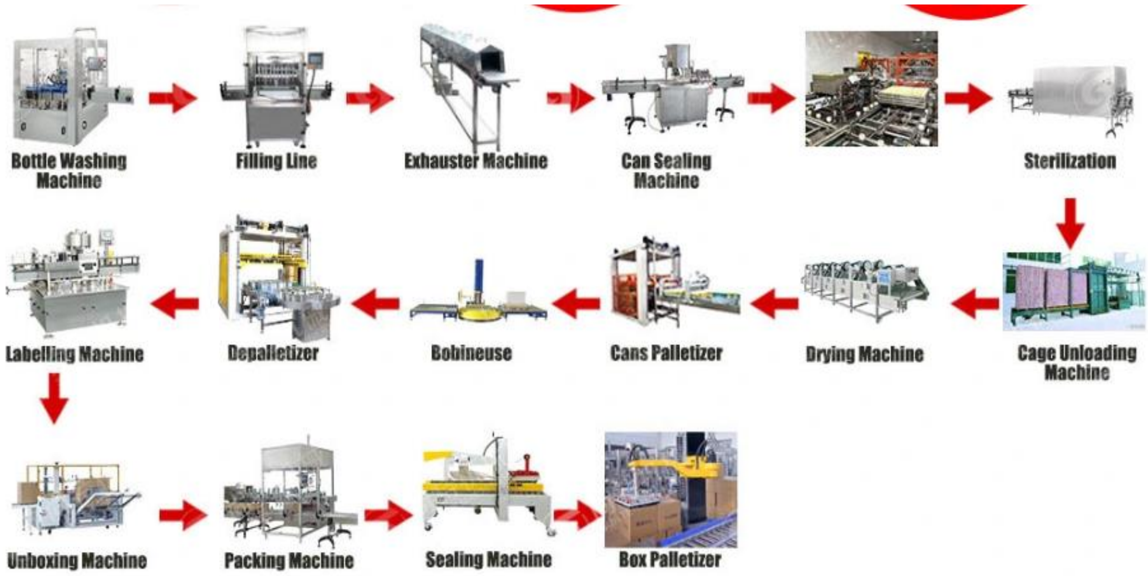


Figure 20: Canned cucumber production line (Source: https://www.suntermachinery.com).

V. COLD PRESERVATION

1. Reminders

Cold preservation requires compliance with the cold chain. Preservation techniques involving lowering the temperature of products and foodstuffs extend their shelf life, and depending on the temperature, cellular activity and the proliferation of micro-organisms are either slowed down or stopped.

Depending on the temperature, cold can be used to preserve foodstuffs from a few days to several months, while preserving their taste and nutritional properties.

2. Pre-refrigeration

Rapid pre-refrigeration is recommended, following as closely as possible the harvesting of vegetables and fruits. Some fragile products are vacuum-packed before refrigeration.

Depending on the nature of the product and the microbiological risks involved, one of the four main pre-refrigeration systems should be used:

- Water cooling: asparagus, leeks.
- Suction cooling: cabbage, lettuce.
- Air cooling: onion.
- Moist air cooling: cauliflower, artichoke.

3. Refrigeration

Refrigeration involves keeping food cool in a refrigerator or cold room. The temperature is generally between 0 and +4°C, depending on the type of product. This method slows down the metabolism of plants and preserves their flavor.

4. Storage in conditioned atmospheres

Some fragile products are vacuum-packed before refrigeration. Modified atmosphere is used as a means of preserving fruit and vegetables. Usually, the effectiveness of modified atmosphere is conditioned by the concentration and quantity of CO_2 available in the gaseous atmosphere, the availability of O_2, the quality of the raw material, and the most important parameter, the storage temperature.

5. Freezing

Freezing food results in a lowering of the temperature to between -18°C and -20°C.

6. Deep-freezing

Freezing is a process that transforms the water in foodstuffs into ice. It crystallizes the water at very low temperatures (below -30°C) and then stabilizes the food at -18°C. It has the advantage of forming only very small ice crystals, thus avoiding tearing the product's cell envelope, unlike slow freezing, which causes larger crystals to form.

When defrosting, on the other hand, frozen products perform better when thawed slowly: they retain their appearance, colors, flavors and all their nutritional elements (Srivastava and Sanjeev, 1998).

Figure 21 presents the flowchart for the preparation of frozen fruits and vegetables.

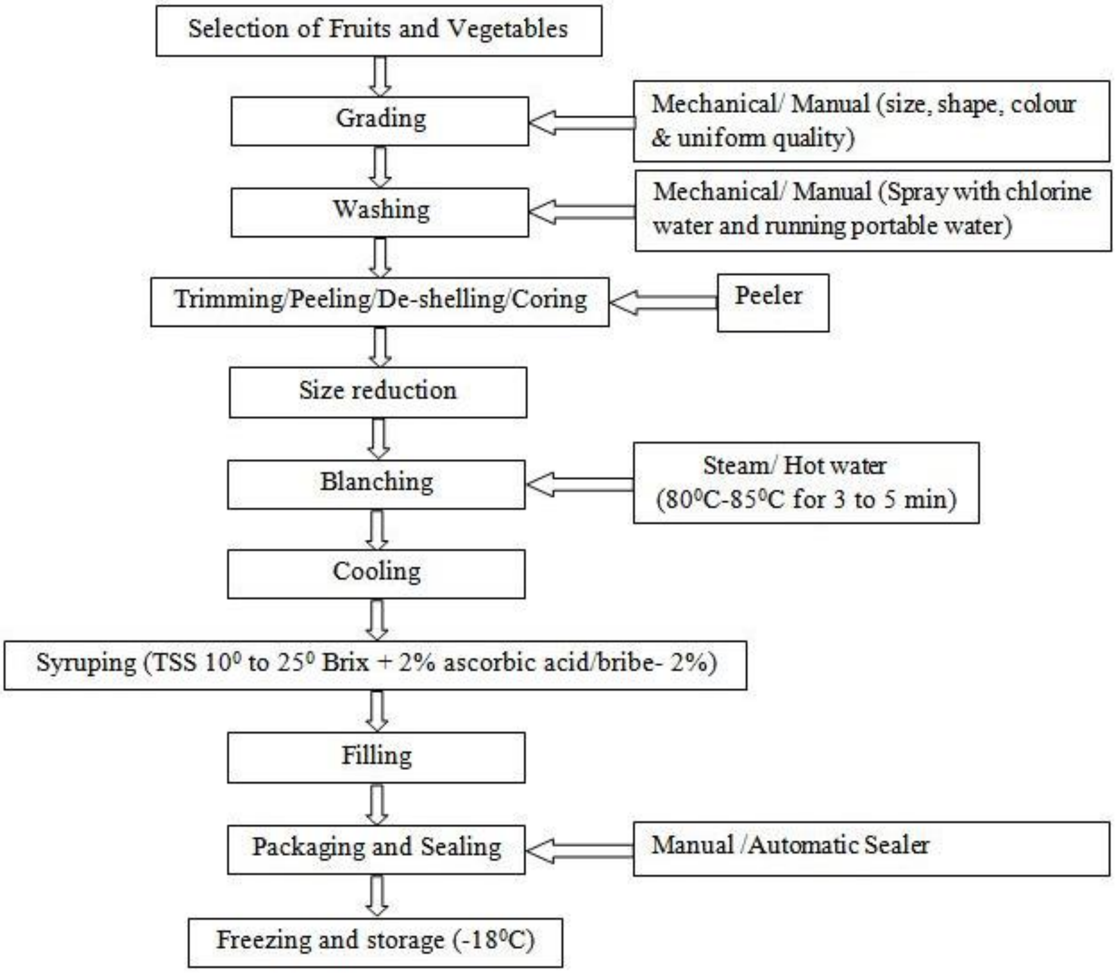


Figure 21: Flow-sheet for preparation of frozen fruits and vegetables (Srivastava and Sanjeev, 1998)

VI. DEHYDRATATION

1. Introduction

Dehydration of fruit and vegetables is one of the oldest food preservation techniques known to man, and consists mainly of plants that sun-dry or artificially dehydrate fruit and vegetables. Although food preservation is the main reason for dehydration, it also reduces packaging, storage and transport costs by reducing both the weight and volume of the final product.

Fruit and vegetable dehydration, also known as “drying”, consists in removing the water contained in fruit and vegetables using heat. By encouraging evaporation of the water contained in the food, the process inhibits the development of the micro-organisms responsible for its degradation (Ratti, 2008).

2. Relationship between drying parameters and food characteristics

Drying is a complex operation involving simultaneous heat and mass transfer phenomena, as well as physical or chemical transformations, which can cause changes in product quality.

Physical changes that can occur include geometric modifications (shrinkage), swelling, crystallization, and glass transitions.

In some cases, desirable or undesirable chemical or biochemical reactions may occur, leading to changes in color, texture, odor, or other properties of the solid product.

The drying phase increases with the higher concentration of polymeric constituents such as proteins and sugars (the latter increase the proportion of water).

Water vapor transfer during the first phase of drying is proportional to the surface area of the food - for example, two half-cubes will dry approximately 1.33 times faster than a single cube of the same weight.

Drying also causes a loss of volatile aromatic substances, a reduction in water retention capacity on rehydration due to heat-induced protein denaturation and aggregation, and a loss of nutritional value (vitamins A and C).

Various dehydration processes can potentially alter the qualities of foods with a high moisture content. Because moisture removal from a material frequently results in changes to the material properties, these changes play an essential part in the design and prediction of heat and mass transfer processes that occur during dehydration (Schumann *et al*., 2022).

Dehydration can have an effect on the stability of important chemicals in plant-based diets. Phenolic substances may be susceptible to enzymatic breakdown due to polyphenol oxidase activity. The elimination of vitamin C and carotenoids throughout dehydration procedures is influenced mainly by water concentration and temperature.

It is also hypothesized that the structural and thermal physical characteristics of fruits and vegetables change during the drying process based on the chemical composition, the physical organization of the structure, the phase distribution of the system, the internal and exterior pore space represented by the porosity, and other factors (Gomez-Lopez *et al*., 2021).

3. Storage of dehydrated foods

Various deterioration reactions can occur during storage of dehydrated foods: insect development, browning, recrystallization of sugars, etc.

Once dehydration is complete, it is advisable to place foods in rigid, well-sealed containers. They should then be stored in a cool place, away from light and humidity.

4. Drying equipment and processes

Drying can be natural or artificial (dehydrators, driers, etc.) (Fig. 22) (Nwankwo *et al.,* 2021):

Open-air dehydration is widespread in many parts of the world, particularly in hot, dry environments. The speed of drying depends on climatic conditions.

The direct solar dryer is simple to use and build, easy to transport and suitable for small-scale production. It features a closed compartment with a transparent, watertight cover, providing insulation.

Oven dehydration uses a conventional or commercial oven.

Atmospheric forced-air dryers artificially dry fruit and vegetables by passing heated air with controlled relative humidity over the food to be dried, or by passing the food to be dried through the heated air. Various devices are used to control air circulation and recirculation.

Subatmospheric (or vacuum) dehydration takes place at low air pressures and includes vacuum rack dryers, vacuum drums, vacuum belts and freeze dryers. The main purpose of vacuum dehydration is to enable moisture to be removed to a level below the boiling point under ambient conditions. There are two categories of vacuum dryers. In the first category, the moisture contained in food is evaporated from the liquid state to the vapor state, and includes rack, drum and belt vacuum dryers. In the second category of vacuum dryers, food moisture is removed from the product by sublimation, i.e. by converting ice directly into water vapor.

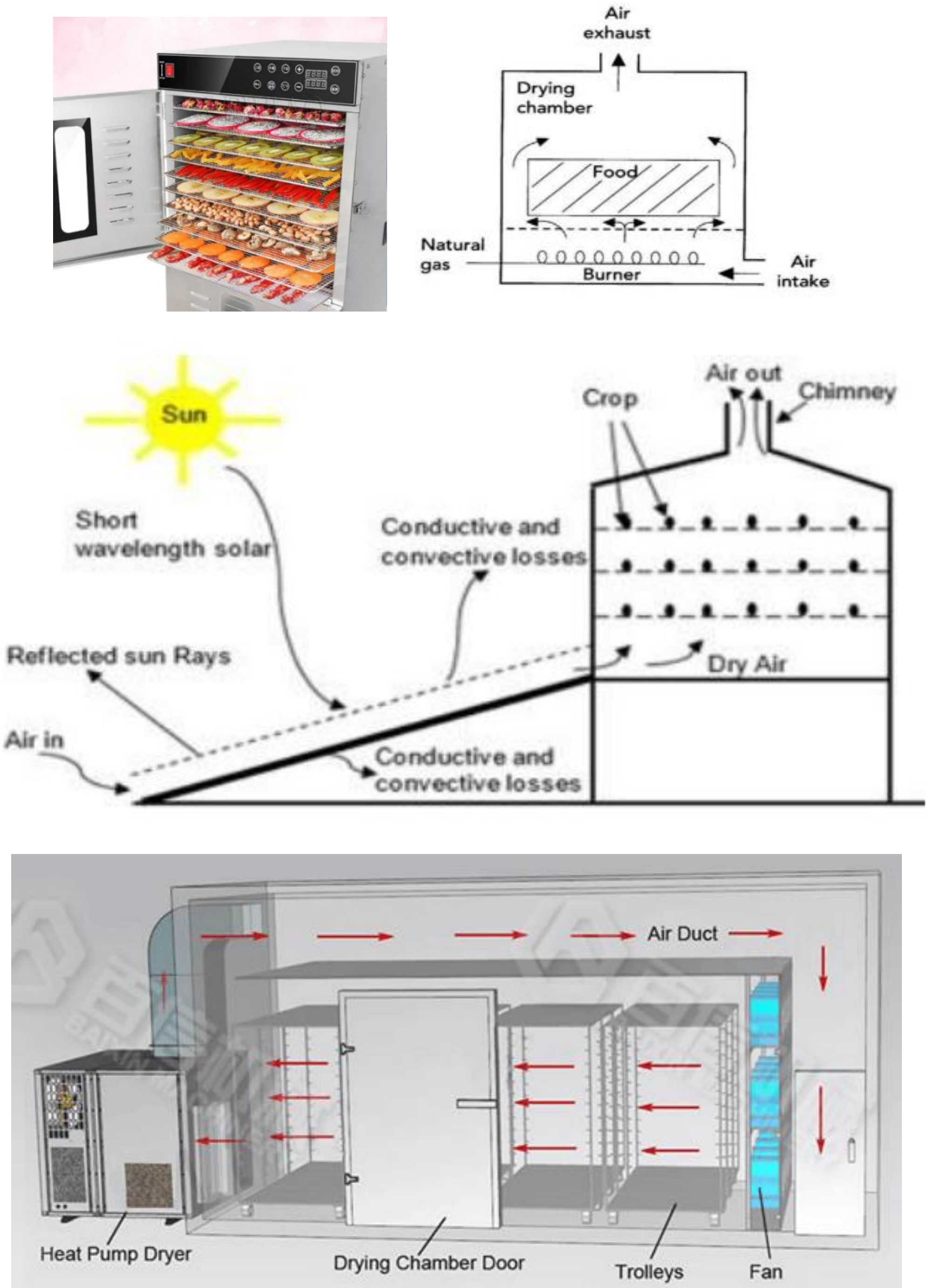


Figure 22: Drying equipments for fruits and vegetables (Nwankwo *et al.,* 2021).

Figure 23 represents the flowchart for the preparation of dehydrated fruits and vegetables.

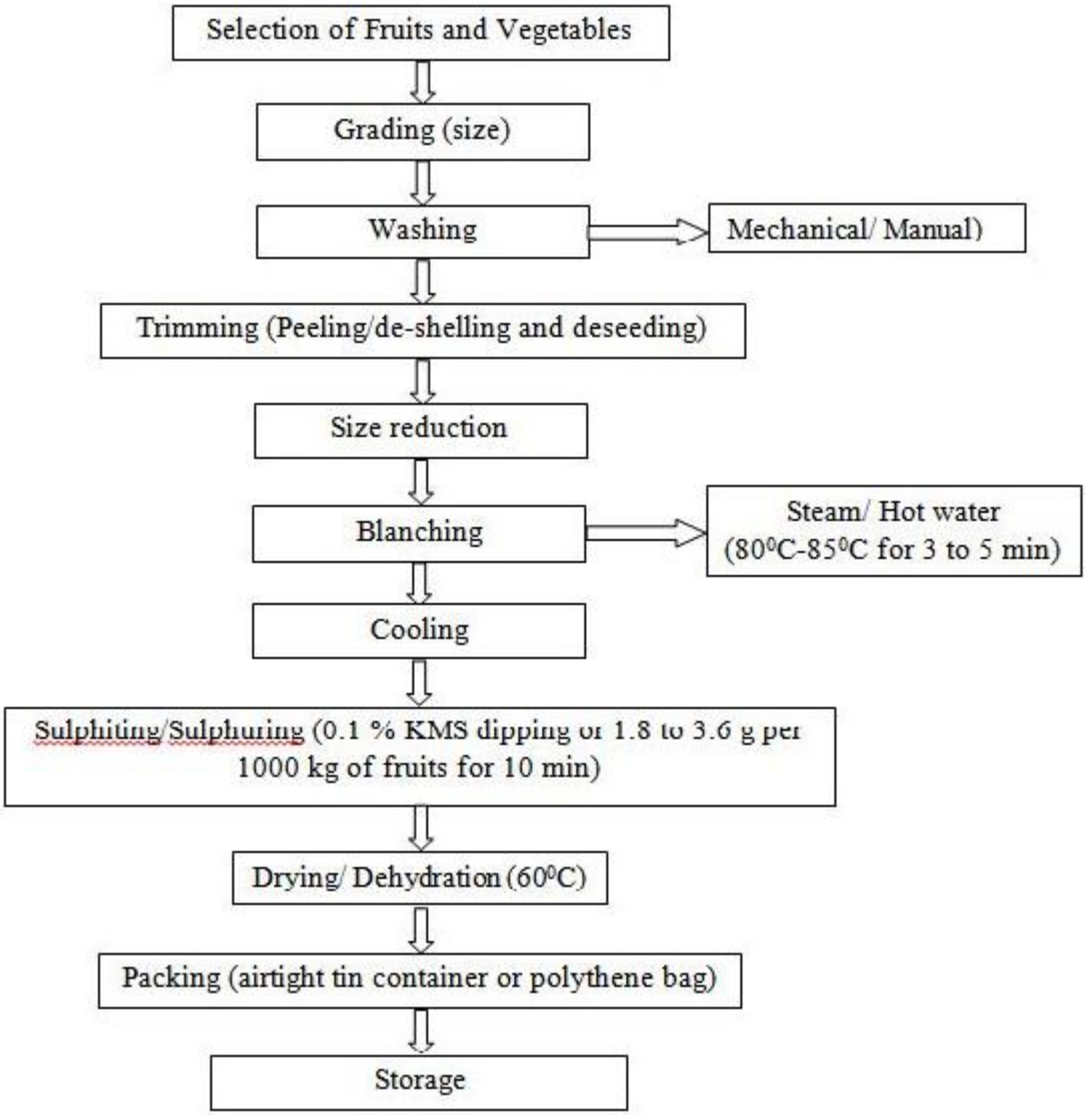


Figure 23: Flow-sheet for dehydrated of fruits and vegetables (Srivastava and Sanjeev, 1998)

5. Freeze-drying

Lyophilization is desiccation by sublimation. This means that the product is frozen and the water evaporated under vacuum, without passing through the liquid phase. The product will then contain only a very small amount of water (1 to 5%). In most cases, freeze-drying preserves the product's appearance, properties and nutritional quality.

Because it functions at lower temperatures and beneath higher pressure, it is the desired technique for dehydrating foods with thermally delicate chemicals and lying to oxidation. Food quality varies as a result of dehydration. Due to the lack of water, oxygen-free atmosphere, and lower temperature conditions, the dehydration of fruits and vegetables through freeze-drying is the optimum method to keep an optimum bio compound content in the final goods (Bhatkar *et al*., 2022).

Table 7 gives a summary of the important drying techniques discussed with their advantages, limitation(s) and application(s).

Table 7: Advantages, limitations and applications of drying methods (Calín-Sánchez *et al.*, 2020).

Drying Method	Mechanism	Advantages	Disadvantages	Application
Convective drying (CD)	Moisture exchange between the food product and the hot air flowing through the drying chamber	Long shelf-life, simple design; Easy operation; Low cost	High inlet gas temperature or very dry gas; Long drying time, exposure to oxidation; Generates o_ flavors; Crust formation on the product surface due to the high temperatures	Food industry; Vegetable and fruit dry products; Pomace processing-functional ingredients production
Spray drying (SD)	Transformation of liquid product into dry powder form in one-step processing operation	Low moisture content and high-quality products; Long shelf-life; Similar size and shape of dried material; Continuous operation Lower cost than freeze-drying	Might lead to bioactive compounds loss and stickiness due to the high temperature, equipment size, products with large fat content require a defat process, high installation cost	Powder production; Microencapsulation; Production of instant powders
Intermittent drying	Intermittent microwave heating is led by applying microwave energy as sequential pulses	Protect bioactive compounds, color, texture; reduce the browning e_ects and enhance the shelf life.	Higher power ratio can damage important compounds such as ascorbic acid.	Plant-based food material; Fruits: kiwi, papaya, banana, guava, carrot, etc.

Table 7 (Continued).

Drying Method	Mechanism	Advantages	Disadvantages	Application
Freeze-drying (FD)	Two steps process: (1) freezing the water from the raw material; (2) heating of the frozen solid to induce the moisture sublimation	Prevents oxidation damages; Minimize chemical compounds changes; Minimal shrinkage and shift of soluble solids; Retention of volatile compounds; Maintenance of porous structure	Very high facilities cost; Slow and expensive process	Production of heat-sensitive compounds i.e., vitamins, microbial cultures, and antibiotics; Production of high-quality products with high final cost: exotic fruits, vegetables, soup ingredients, mushrooms, and juices
Osmotic dehydration (OD)	Moisture reduction by immersion of the raw material in a high osmotic pressure solution! moisture transfer from the food to the solution driven by the di_erence in osmotic pressure	Maintenance of the physicochemical and sensory parameters; When carried out in concentrated juices might enhance product quality	High final moisture content; Usually needs further drying; High content of sugar or salt in the product when dehydrated in this type of solution; Di_culty in predicting final chemical composition when dehydrated in concentrated juices	Fruit chips production; Production of dried fruits i.e., plums as a pre-treatment before further drying

VII. CHEMICAL TRAITEMENTS

1. Chemical treatments that do not alter the organoleptic characteristics of foodstuffs.

- **Addition of preservatives** (E200 to E 297) example: sulfur compounds such as sulfites (E 221 to 228); nitrates and nitrites (E 249 to 252); benzoic acid and its calcium, sodium and potassium salts (E 210 to 213).
- **Addition of antioxidants**: example: ascorbic acid (E300-E302).
- **Addition of acid**: example: lactic acid (pH = 4: microorganisms will not grow) (Pașca *et al*., 2018).

2. Treatments that modify the organoleptic characteristics of foodstuffs

- **Oil preservation**

Oil acts as a barrier to water and air.

- **Preservation with salt**

Salt is used in different doses, depending on preservation requirements: at 2%, it slows down the development of certain micro-organisms and imparts a salty taste; at high doses, it destroys almost all micro-organisms. The presence of salt reduces the activity of water in a product, thus slowing or stopping the development of micro-organisms.

There are two techniques using salt: salting (= curing: preservation using dry salt or water + salt) and brining (aqueous solution of 20% salt = 200g salt + 65 ml vinegar per liter of water).

- **Preservation with sugar**

Preservation with sugar can only be achieved when the food is hot. The food must lose some of its water content through evaporation, and the sugar must dissolve to bind to the remaining water molecules, making them unavailable to micro-organisms. This method is mainly used to preserve fruit.

3. Fermentation

The most widely used fermentation method is lacto-fermentation (especially for vegetables).

Lacto-fermentation is a living preservation method based on the presence of salt and the absence of oxygen. These two factors limit the growth of harmful micro-organisms and favor *Lactobacillus*. They feed on the carbohydrates present in food and transform them into lactic acid. The preparation becomes increasingly acidic, neutralizing the development of bacteria responsible for putrefaction. As the acidity increases, the lactic acid bacteria are in turn inhibited. The result is a stable preparation that can be preserved for a long time.

The benefits of lacto-fermenting fruit and vegetables include (Patel *et al*., 2023):

- Advantageous preservation: long-lasting, easy, healthy, safe, economical, environmentally friendly.
- No loss of nutrients, unlike most other preservation methods.
- Improves the nutritional value of foods (especially minerals and vitamins).
- Produces peptides and enzymes with hypotensive, prebiotic, antimicrobial, anti-carcinogenic, antioxidant, antifungal, anti-inflammatory, anti-diabetic, anti-atherosclerotic and other effects.
- Improves the digestive system (intestinal health, microbiota balance, inflammation, constipation, etc.).
- Eliminates pesticides.
- Unique flavor: changes the taste of the food.

VIII. IONIZING RADIATION TREATMENTS

1. Reminders

Food irradiation, also known as food ionization, is one of the cold pasteurization processes, because it exposes the food to ionizing radiation and does not involve any heat treatment, while aiming to preserve the food. Gamma and X-rays are used (Fig. 24) (Bisht *et al*., 2021).

2. Main effects on food

- **Induced radioactivity:** At high energy levels, ionizing radiation can render certain food constituents radioactive.
- **Alteration of organoleptic characteristics:** Chemical transformations produced by food irradiation can have a noticeable effect on flavor. Doses of 1 to 3 kGy soften certain fruits (cell membranes burst).
- **Changes in nutritional value:** At average doses of 1-10 kGy, a certain loss of vitamins can be observed in foodstuffs exposed to air during irradiation or storage. Some vitamins, such as riboflavin, niacin and vitamin D, are relatively insensitive to irradiation. Others, such as vitamins A, B1 and E, are more easily destroyed.

- **Effects on micro-organisms:** Micro-organisms (especially Gram-negative bacteria such as salmonella) can be destroyed by irradiation. Bacterial spores, on the other hand, are only destroyed at high doses, so irradiation does not exclude with certainty the risk of botulism, for example.

3. Application

The practical applications of food irradiation most often concern food preservation. Radiation inactivates spoilage agents, i.e. bacteria, moulds, yeasts, parasitic worms and harmful insects.

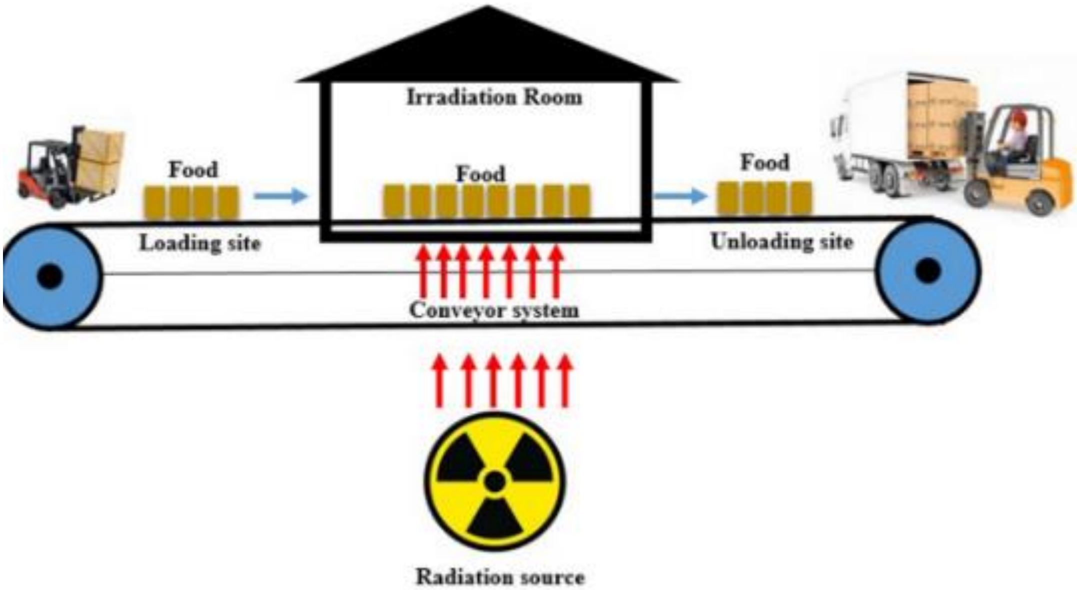
This technique effectively increases the shelf-life of fresh fruit and vegetables by slowing down the normal biological transformations associated with ripening, ripening, germination and, ultimately, ageing.

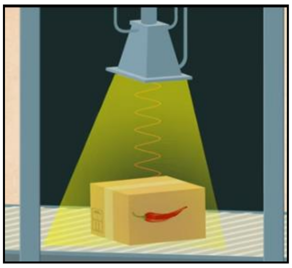
The radiation dose, i.e. the amount of radiant energy absorbed by the food, is the most decisive factor in food irradiation. The radiation dose recommended by the FAO/WHO Codex Alimentarius Commission for food irradiation does not exceed 10,000 grays, which is usually written as 10 kGy.

Two types of food irradiation facility are available: continuous and batch.

In continuous irradiation systems, food circulates through the cell at a set speed, calculated to ensure that all foods receive exactly the right dose.

In batch systems, a given quantity of food is irradiated over a specific period of time. The cell in which the irradiated food has been placed is then unloaded, and a new batch is put in place, which is in turn irradiated (Bisht *et al*., 2021).





Irradiated food using Gamma rays

International food irradiation symbol

Non-irradiated strawberries

Irradiated strawberries

Figure 24: Food irradiation.

Part 3

MEAT AND FISH TECHNOLOGY

PART 3: MEAT AND FISH TECHNOLOGY

I. ISSUES IN THE MEAT SECTOR

In Algeria and throughout the world, the meat industry plays an important role in human consumption and makes a significant contribution to the national and international economy. Unfortunately, this sector faces a number of challenges, from animal production to meat consumption. Among the challenges facing the meat industry, several major issues stand out, touching on environmental, economic, health and ethical aspects:

1. Environmental impact

- **Greenhouse gas emissions**: Livestock farming is responsible for a significant proportion of global greenhouse gas emissions, notably via the methane produced by ruminant digestion. The FAO estimates that the livestock sector contributes around 14.5% of global GHG emissions, making the meat industry a key player in the climate change debate.
- **Use of natural resources**: Meat production requires a significant amount of natural resources, such as water and farmland. Forage cultivation and intensive livestock farming contribute to deforestation, exacerbating the loss of biodiversity. The activities like slaughtering and dressing of animals, cleaning of equipment and premises, washing of transport vehicles and meat handlers, and processing of by-products require water and energy (Petrovic *et al*., 2015).

2. Animal welfare

- **Farming conditions**: Intensive factory farming, with practices such as confining animals to small spaces, raises many ethical concerns.
- **Transport and slaughter**: The long distances animals travel to reach slaughterhouses, as well as slaughter methods, have led to criticism of animal stress and suffering, prompting a review of standards.

3. Sanitary safety and public health

- **Antibiotic resistance**: The intensive use of antibiotics in livestock farming, often to stimulate growth or prevent infections, has a direct impact on the increase in antibiotic resistance. This phenomenon represents a major threat to public health, as it reduces the effectiveness of treatment in humans.
- **Risk of contamination**: Meat can carry pathogens such as *Salmonella*, which can lead to food poisoning. Sanitary control of meat throughout the production chain is therefore crucial to ensuring food safety.
- **Environmental pollution**: All the water consuming activities in the animal farm generate huge quantities of wastewater. Wastewater gets mixed with various organic and inorganic materials like manure, urine, blood, hair, fat, stomach and intestinal contents, feathers (poultry), cleaning agent, chemicals, packaging material etc. from different areas. All these lead to environment pollution and obnoxious odor (Sinhamahapatra, 2022).

4. Economic competitiveness

- **Pressure on small-scale producers**: The industrialization of meat production and the dominance of large multinationals are putting pressure on small-scale producers, who are struggling to remain competitive.
- **International trade**: Trade agreements influence the dynamics of the meat industry, with low-cost imports from countries with less stringent production standards, which can disadvantage local producers in developed countries.

II. OVERVIEW OF MEAT COMPOSITION AND STRUCTURE

1. Overview on the raw material

Meat, as a raw material, is an essential food resource in the human diet. It is derived mainly from the muscle tissue of terrestrial animals such as cattle, sheep, pigs and poultry, as well as certain species of aquatic animals. Meat is a valuable source of nutrients, offering high-quality proteins, lipids, vitamins (notably B12) and minerals (such as iron and zinc).

The carcasses of land animals are made up of several types of tissue: muscular, connective, adipose, blood, nerve and bone. Each of these contributes to the organoleptic qualities of the meat: muscle and connective tissue to tenderness, blood tissue to color, adipose tissue to flavor, and so on.

2. Composition and structure of meat

Muscle is a collection of muscle fibers grouped into bundles and surrounded by connective tissue, the latter mainly composed of collagen. The diversity of whole muscle cuts in beef reflects varied arrangements of muscles and fat, contributing to the unique characteristics of different steak types. These variations are influenced by multiple factors, including the animal's breed, growth conditions, feed, age, and butchery techniques, such as the specific area of the cut, meat aging, and processing conditions (Dikovsky, 2024).

There are three types of connective envelope (Fig. 25):

- Epimysium: a sheath enveloping the entire muscle ;
- Perimysium: a sheath enveloping a group of muscle fibers;
- Endomysium: a sheath surrounding each muscle fiber.

Three categories of fibers:

- Fibers with glycolic energy metabolism and rapid contraction;
- Fibers with oxidative energy metabolism and slow contraction;
- Intermediate-energy metabolism fibers.

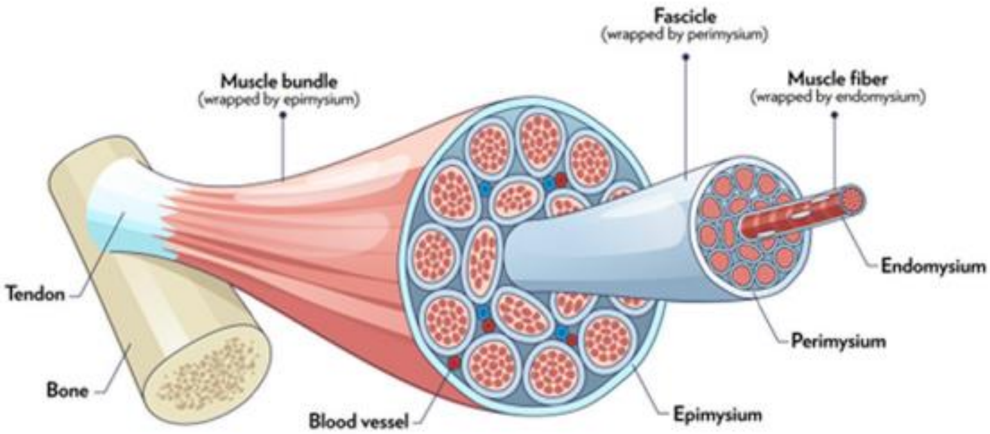


Figure 25: Meat structure (Dikovsky, 2024).

Muscle is composed mainly of proteins, lipids, carbohydrates and water. The composition of meat varies according to:

- Animal species;

- The animal's sex, age and diet;

- Anatomical placement of the meat.

The breakdown of the main constituents of muscle is given in Table 8.

Tableau 8: Typical percentage composition of some Meats with medium amounts of fat (Ivanović *et al*., 2016).

Meat	Protein	Fat	Ash	Water
Beef	17.5	22.0	0.9	60
Veal	18.8	14.0	1.0	66
Lamb	15.7	27.7	0.8	56
Horse	20.0	4.0	1.0	74
Chicken	20.2	12.6	1.0	66
Duck	16.2	30.0	1.0	52.8
Turkey	20.1	20.2	1.0	58.3

- **Muscle proteins**

1. Stromal proteins (connective tissue)

a. Collagen

These are the least soluble proteins, fibrous and extracellular. They are the most abundant proteins. They account for 50% of total connective tissue proteins. They are structural proteins. The solubility of collagen in saline or acidic solutions decreases with age. Collagen in aqueous medium becomes gelatinous at 80°C. In cooked meat, tenderness depends solely on denatured muscle fibers and elastin.

b. Elastin

Elastin is an abundant protein in artery walls. It has a fibrous structure and is resistant to most proteases (pepsin, trypsin, chymotrypsin). It is partially hydrolyzed by pancreatic elastase. It is not attacked by relatively concentrated acids and bases.

2. Sarcoplasmic proteins

The sarcoplasmic proteins include hemoglobin and myoglobin pigments and a wide variety of enzymes. eg myogen, myoalbumin and x-globulin. Pigments from hemoglobin and myoglobin help to contribute the red color to muscle. Hemoglobin carries oxygen from the lungs to the tissues— including muscle. Myoglobin is present in muscle and it stores the oxygen transported to the muscle via the blood by hemoglobin until it is utilized in metabolism.

Hemoglobin is the main pigment in meat; it accounts for 90% of total pigments in beef muscle, and is responsible for the red color.

3. Muscle fibers

The muscle fiber is a long cell, measuring 1 mm to several cm in length and 10 to 100 µm in diameter. It is made up of 100 parallel filaments 1 µm in diameter called myofibrils (Belk, 2015).

III. PRIMARY PROCESSING: SLAUGHTERING

1. Cattle and sheep slaughtering operation

a. **Bringing in:** animals are brought to the slaughter bays (parking time must not exceed 1 h).
b. **Entry into the stunning box:** the animal must enter the box completely and the head is immobilized to facilitate stunning.
c. **Stunning: (not intended for Halal slaughter)** aims at the loss of consciousness and is performed before the animal is killed. The most widely used method is stunning with a high-performance rod gun (specific cartridges and different doses are available). There are also electric clamps (200 volts) which are applied for 3 seconds. Stunning lasts a few minutes; e.g. 3 min for cattle, between stunning and bleeding.
d. **Stunning/suspension:** transfer of animals from stalls (on conveyor belt)/transfer of animals to the slaughterhouse's overhead handling system.
e. **Bleeding:** this operation consists in cutting certain blood vessels in order to empty the animal of as much blood as possible from its circulatory system. It causes the animal's death.
f. **Skinning:** involves removing the animal's skin.
g. **Evisceration**: During this stage, the head and giblets are removed.
h. **Post-mortem inspection:** At this stage, the veterinarian has 3 options:

- Stamping, if the animal is fit for consumption.
- Consignment, pending further analysis. If the analyses are positive, the animal is stamped.
- Seizure, which can be total or partial; if the animal is unfit for consumption, it will be incinerated (Fig. 26) (Singh and Cross, 2022).

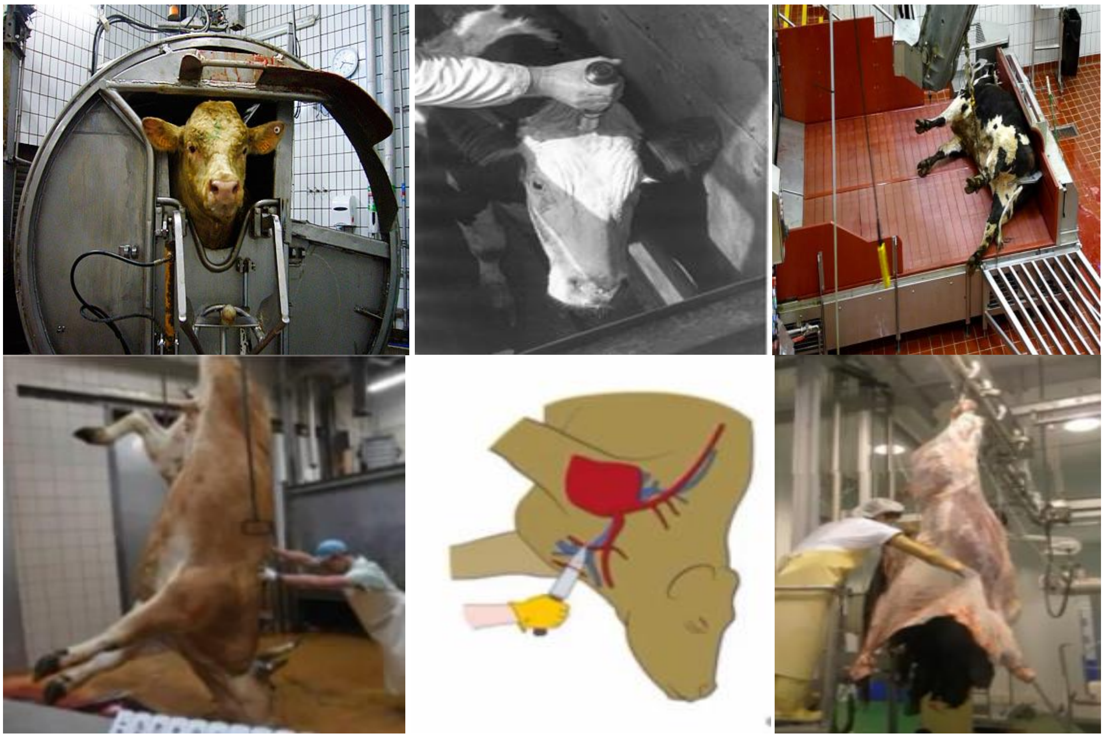


Figure 26: Cattle slaughter line.

2. Poultry slaughtering operation

a. **Poultry reception:** chickens are hung on stainless steel shackles on the slaughter line.
b. **Stunning (not for Halal slaughter)**: Electric water-bath stunning is the most common method used in commercial slaughterhouses. After hanging, heads are immersed in an electrified water bath, passing current through the head and body, inducing unconsciousness.
c. **Head cutting:** Halal slaughter requires a professional slaughterer to kill the chickens as quickly as possible using professional equipment.
d. **Bleeding:** Chickens must be bled as they move through the transfer line.
e. **Scalding:** Chickens should be scalded for better de-foaming. Scalding requires appropriate water temperature and duration without skin damage.
f. **Chicken pluckers:** After scalding, plucking is more accessible than before with the automatic plucker.

g. **Evisceration:** This section is equipped with special tools to facilitate evisceration of chicken viscera.

h. **Chicken leg cutting:** performed by a sharp, hard foot cutter.

i. **Pre-cooling:** The screw pre-cooling machine plays a role in cleaning, cooling and deacidifying the carcass after slaughter in the poultry slaughter line process. The poultry carcass after slaughter is still hot. If it is not cooled and cleaned, it will deteriorate during the subsequent preservation process and is not easy to preserve. Consequently, the poultry carcass must be cooled after slaughter. The pre-cooling time is approximately 30 minutes. The water temperature is around 0-4 °C (Fig. 27) (Kumar *et al.*, 2022).

Figure 27: Poultry slaughter line.

IV. PROCESSING OF SLAUGHTER BY-PRODUCTS, VALORIZING THE 5th QUARTER

The elements of the 5th quarter are all the elements coming from the slaughtered animal that are not designated under the term meat, such as offal, blood, fat, skins, etc. (Fig. 28).

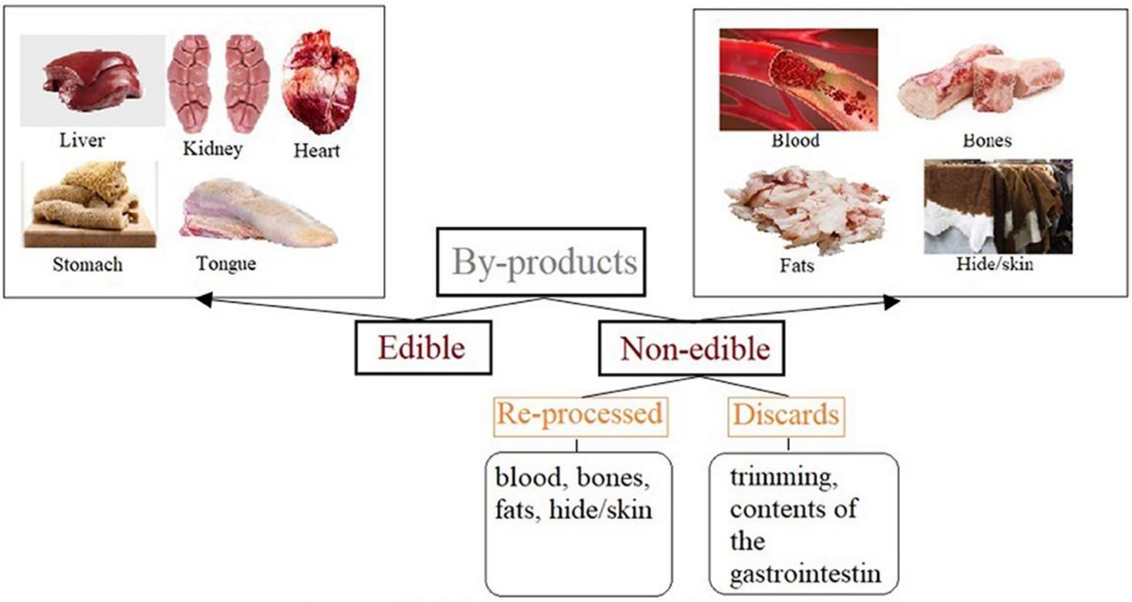


Figure 28: Edible and non-edible by-products (Alibekov *et al*., 2024).

The different value-adding circuits (Table 9):

- Human food: consumption of offal/use of fats as gelling agents (gelatin).
- Soil fertility and animal feed: blood and bone co-products are highly nutritious.
- Manufacturing of shoes, upholstery, clothing, furniture, etc.: from skins.

Table 9: Uses of meat industry by-products (Sinhamahapatra, 2022).

Primary by-product	Uses
Hide/skin	Leather, collagen
Bone	Bone meal, gelatine
Blood	Food ingredients, blood meal, serum, plasma, gelatine, bioactive peptide
Fat	Cooking fat, lubricant, soap, cosmetics, biodiesel
Stomach and intestine	Casing, tripes
Organs like glands, lungs, brain	Food ingredients, pet food, pharmaceutical uses like hormones, enzymes
Horn, hoof/feet	Keratin, horn/hoof meal, artefacts
Feather	Artefacts, feather meal
Hair, bristles, wool	Brush, carpet, garments
Inedible carcass or parts	Carcass meal, animal feed, fertilizer
Stomach and intestinal content	Animal feed, fertilizer, biogas

In the food industry, around 30% of the total volume of blood is used as a gelling agent and natural colorant.

One of the most valuable products is blood flour, which is an insoluble dried blood powder containing at least 80% protein, 3% fat, 6% ash and less than 10% moisture (Fig. 29).

Spray-dried plasma can be used as an egg substitute in bakery products due to the foaming and leavening properties of blood plasma proteins.

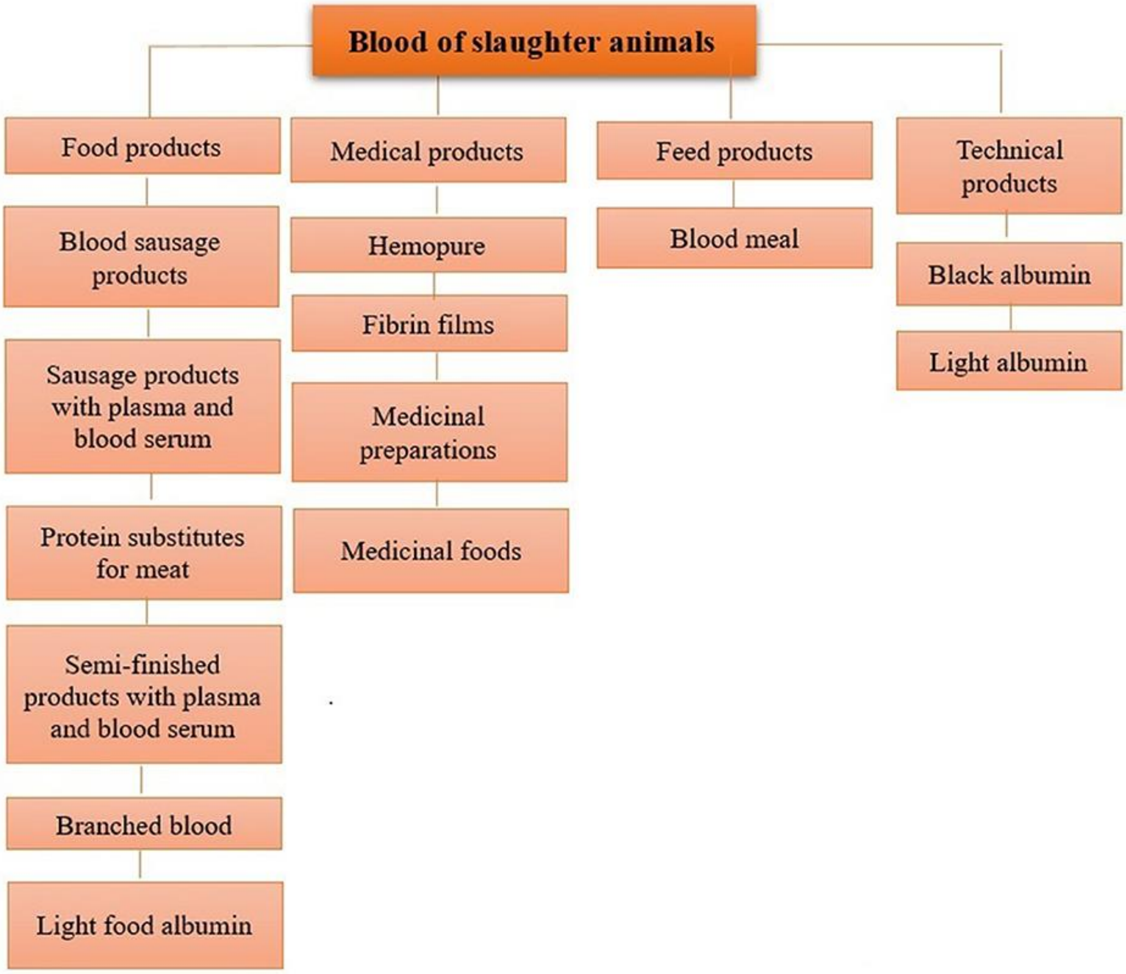


Figure 29: Application of waste blood (Alibekov *et al.*, 2024).

Blood processing enables it to be separated, dehydrated, and valorized (Fig. 30). In fact, animal blood is made up of a mixture of plasma, a functional protein with commercial potential for human consumption.

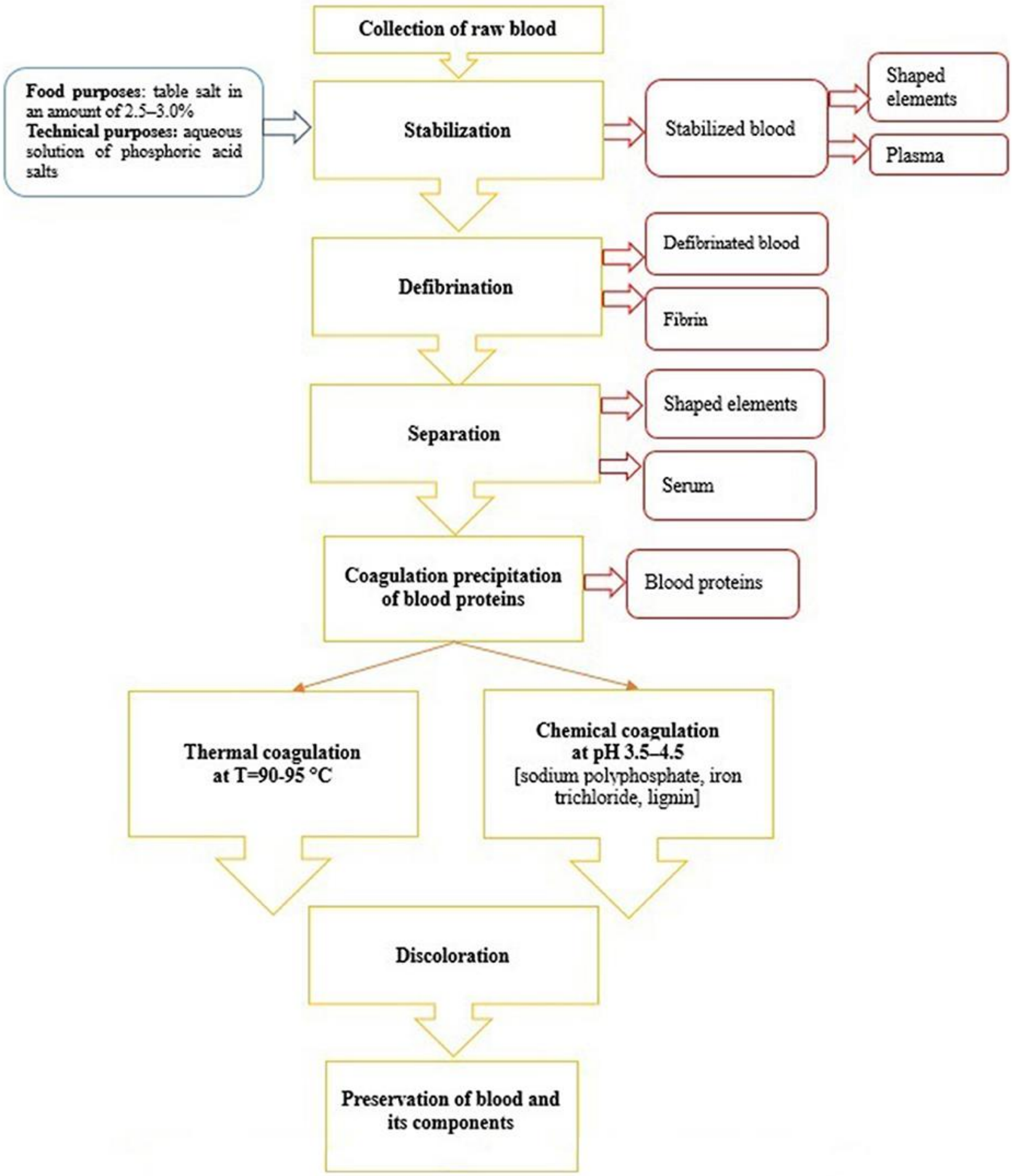


Figure 30: Blood treatment diagram (Alibekov *et al*., 2024).

V. FISH

1. Composition

Fish generally contain between 60% and 80% **water**, depending on the species and state of freshness. Water is the main element and influences the texture, preservation and quality of fish. Lean fish generally have higher water content, while fatty fish contain less.

Fish are rich in high-quality **protein**, ranging from 15% to 25%. Fish proteins are easy to digest and contain all the essential amino acids, making them particularly nutritious. The main muscle proteins include actin, myosin and tropomyosin, responsible for muscle structure and contraction.

Fish are classified according to their **lipid** content: lean fish (less than 5% lipid content, such as cod), semi-fat fish (5% to 10% lipid content, such as trout) and fatty fish (more than 10% lipid content, such as salmon or mackerel). Oily fish are rich in polyunsaturated fatty acids, notably omega-3s (EPA and DHA), which are beneficial for cardiovascular health and brain development. These fatty acids are particularly present in marine fish.

They are also an excellent source of essential **minerals**, including phosphorus, potassium, magnesium and calcium. Iron is also present, but its bioavailability is lower than that of red meat. Marine fish are an important source of iodine, essential for thyroid function.

Fish also provide fat-soluble **vitamins** such as A, D and E. Oily fish such as salmon and tuna are rich in vitamin D, which aids bone health. They also contain B vitamins (B6, B12, niacin), which play a crucial role in energy metabolism (Omidvar *et al.*, 2024).

2. Nature

- **Muscle**

The edible part of the fish, the fillet, is made up of several muscles: the **myogenes**, nested inside each other and separated by a connective tissue partition a few millimeters thick, called the **myosept.**

This particular organization, with alternating muscular and connective layers, forms a structure known as **metameric** (Fig. 31).

This structure also makes fish flesh more tender and easier to split than meat from land mammals. The proportion of connective tissue is lower, which promotes tenderness.

- **Fatty tissues**

Fatty fish accumulate fat reserves mainly in the muscles and under the skin. In lean fish, fat is mainly stored in the liver.

- **Bones**

Fish have a skeleton made up of fine bones, with bones that vary in size and number depending on the species

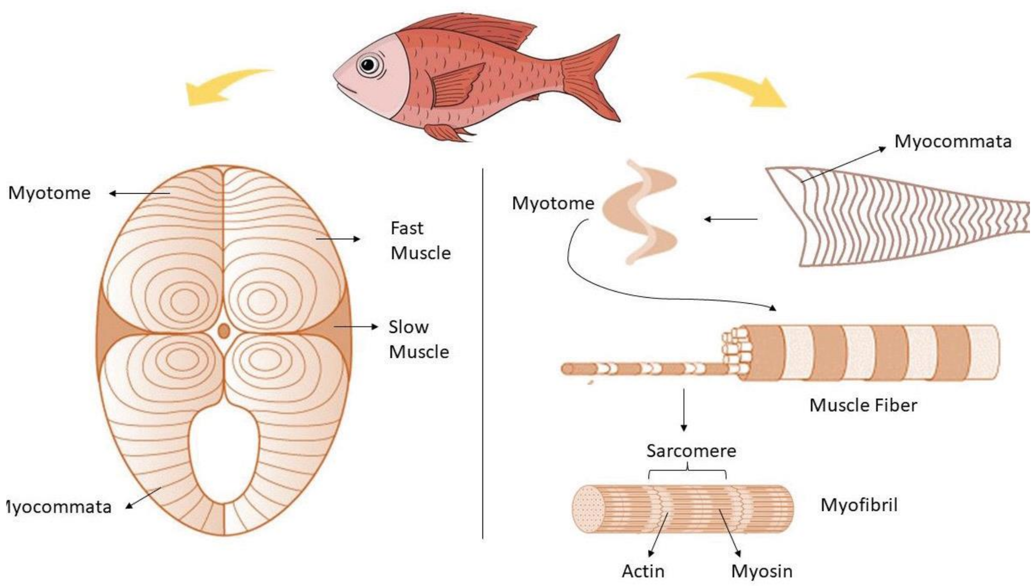


Figure 31: Nature and structure of a fish (Omidvar *et al.*, 2024).

VI. COLD TREATMENT OF MEAT AND FISH

1. Refrigeration

Low temperatures slow down (bio) chemical, physical and microbiological processes and prevent spoilage.

Meat refrigeration requires the use of a cold room. To preserve meat, the temperature of the carcass must be rapidly lowered from around 40°C to 0-5°C, in order to limit microbiological degradation on the surface of the meat. After this initial cooling, the meat is either chilled or frozen.

Refrigeration from -1°C to +3°C can be useful during the time between slaughter and sale, or during long transport. Meat refrigeration is also used to mature meat, making it more tender.

Fish is generally cooled by placing it on ice, which requires the use of ice-making machines.

Fish can also be stored in refrigeration cells: as the temperature is just above 0°C, the ice melts and the fish stays fresh. So the fish doesn't freeze.

2. Freezing

Freezing to -18° completely stops bacterial growth.

Frozen meat is generally stored between -12°C (10°F) and -20°C (-4°F). At this temperature, beef has a shelf life of at least 1 year.

Fish can be frozen for 2-3 weeks. The recommended freezing temperature is -30°C / -22°F. To obtain good-quality fish, you need to freeze it immediately after fishing (it keeps for a very long time).

By definition, the freezing process of muscle food refers to the decrease in random movement of the water molecules present in the tissue (Fig. 32). The freezing of water in meat can be summarized in three distinct chronological stages:

1. Cooling the product to its freezing point;

2. The phase transition stage, during which latent heat is eliminated; it is during this transition phase that water molecules are crystalline oriented and ice crystals are formed.

3. Product reaches final storage temperature (tempering).

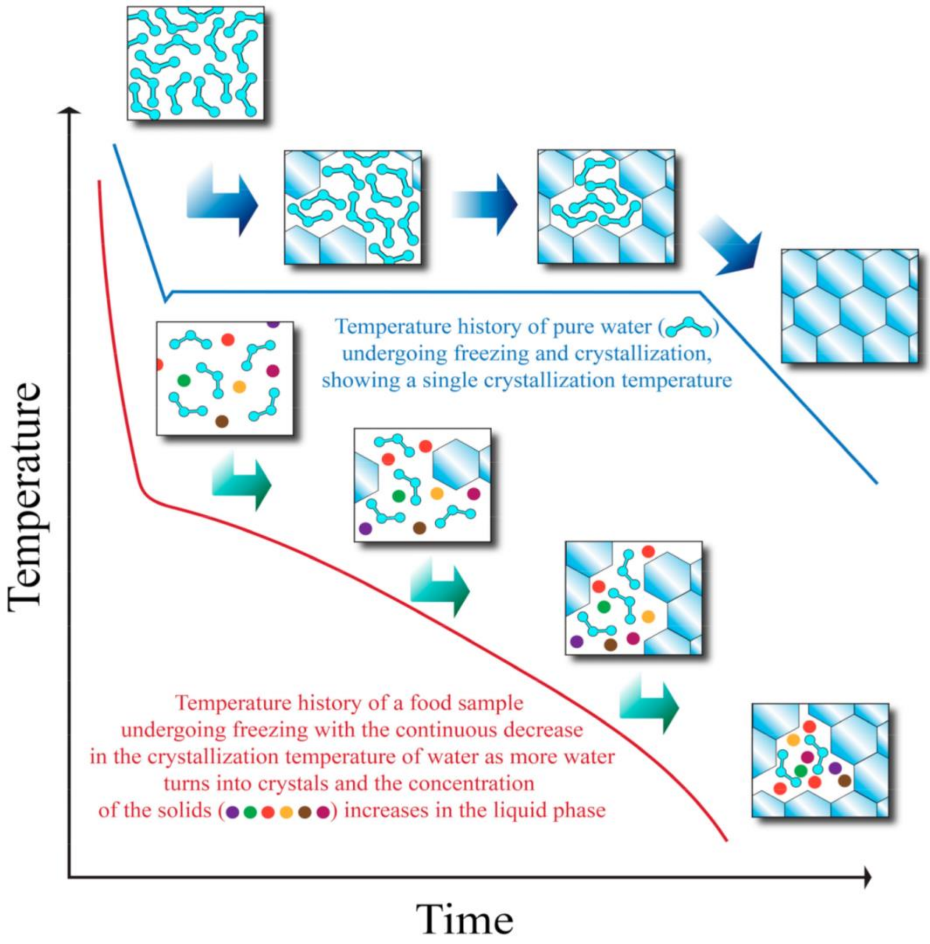


Figure 32: Temperature history of pure water and a food sample during freezing (Dang *et al*., 2021).

The rate of cooling during freezing can have a considerable influence on the microstructure and overall quality of the meat (Fig. 33):

- A slow cooling rate favors the formation of large ice crystals and, consequently, more pronounced deformation of the original cellular structure. In meat, large crystals can also mechanically damage myofibrillar structures and cause a reduction in water holding capacity (WHC), which in turn has a negative impact on product color, flavor and juiciness.

- On the other hand, higher cooling rates result in smaller crystals and therefore less damage to the cell structure. This is why rapid cooling speeds are preferred for freezing food products in general and meat products in particular.

3. Quick freezing

Carcasses or large cuts of meat are deep-frozen at -30 to -40°C in a forced-air chamber. This technique enables the formation of numerous small ice crystals that do not deteriorate the food. Only a slight exudate is produced during thawing.

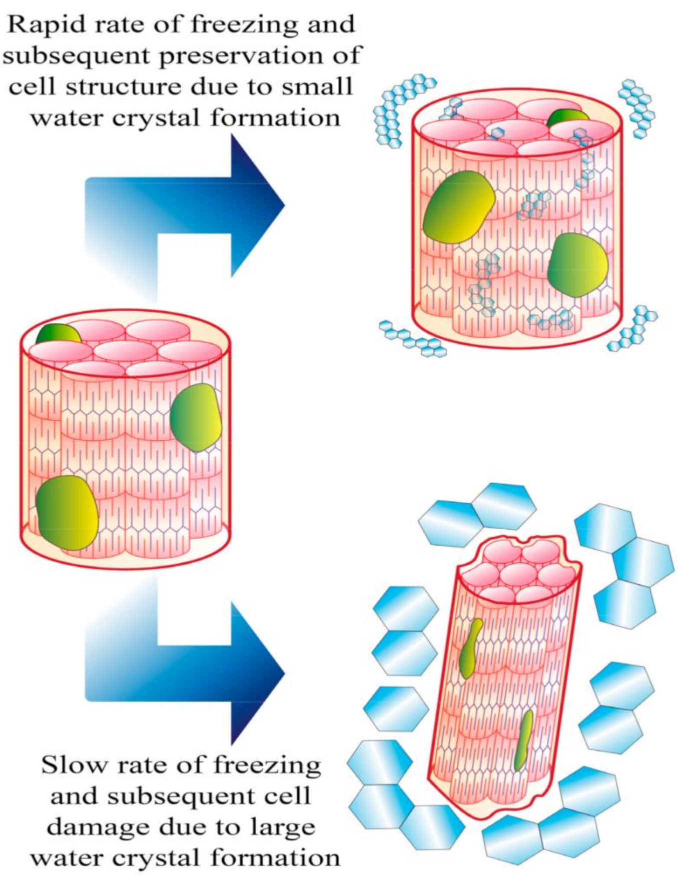


Figure 33: Effects of cell integrity at different speeds of cooling and water crystallization (Dang *et al*., 2021).

VII. PRODUCTS OF THE TERTIARY PROCESSING OF MEATS

1. Technologies used in Algeria: Cooking, Mincing, Salting

The products of 3rd transformation correspond to the piecing of muscles to the manufacture of elaborated products such as: minced steak, sausages, pâtés...

Several technologies are currently used in Algeria for 3rd transformation products:

- Curing: using salt and sodium or potassium nitrite. This technique improves color, gives a typical taste and ensures good preservation.
- Drying: especially for dried meat and salami (the ideal drying temperature is 10-14°C).
- Heat treatment: for canning.
- Smoking: carried out in wood-burning smokehouses. This technique is used to flavor products and accentuate surface color.
- Mincing: involves mechanical separation of muscle and bone, shredding and grinding (e.g. cachir).
- Cooking: generally combined with other preservation methods (e.g. ready meals).

In recent years, traditional food products including meat-based ones have been increasingly regaining consumer interest worldwide. Different meat products are prepared using one or mix of techniques, and there exist meat products that are usually dried (e.g., guedid), smoked, fermented, roasted, cooked, and some of them are fried.

The preparation of most of North African meat products had their own typical organoleptic characteristics, which are mainly attributed to the spices and herbs added during seasoning (Gagaoua and Boudechicha, 2018).

The most common ethnic meat products of Algeria are cited in Table 10.

Table 10: List of the most common ethnic meat products of Algeria (Gagaoua and Boudechicha, 2018).

Meat product	Livestock source	Main ingredients	Steps of preparation
Melfouf	Lamb	Salt, pepper, and hot red pepper	Trimming, cutting, seasoning, and roasting
Merguez	Lamb, beef, buffalo, and poultry	Salt and spices	Grinding, mixing, and stuffing
kefta	Lamb, beef, and poultry	Salt, spices, smashed onion, fresh minced garlic, minced parsley	Mincing, mixing, grilling, and roasting
Typical guedid	Beef, lamb, goat, and camel	Salt	Trimming, salting, and sundrying
El M'selli	Beef and lamb	Salt, pepper, fresh garlic, hot red pepper	Cutting, salting and curing, sundrying, and ripening in melted bovine fat
Maynama	Lamb, beef, goat, and camel	Salt and spices	Cutting, seasoning, and smoking
Merdouma	Beef, lamb, camel, goat, and poultry	Salt and spices	Seasoning and smoking
Khliaa	Beef, lamb, goat, and camel	Salt, coriander, caraway, fresh garlic, olive oil, and animal fat	Trimming, curing, cooking, and ripening in earthenware jar
Osbana	Lamb	Salt, spices (red hot pepper, garlic, coriander, parsley, and ginger), rice, and chickpea	Cutting, seasoning, stuffing, and cooking
Cachir	Beef, lamb, goat, and camel	Salt, spices, and olives	Grinding, mixing, steaming, and cooking

2. Structuring of fine pastes (pâté, cachir)

2.1. Definition and structure of a fine paste

A fine paste is a mixture of ground meat and/or liver, fat, water, ingredients and additives, ground to a very homogeneous consistency. It can be used on its own or mixed with other ingredients (olives, cheese, etc.).

Fine paste can be produced using two main technologies:

- Cold processing, which produces products with a sliceable texture, such as sausages and cachir; this is a fine meat paste;
- Hot production, leading to products with a spreadable texture, such as liver mousses.

2.2. Pâté-making technology

Pâté is a meat preparation based on meat (often poultry or game), liver, fat and seasonings. It can be cooked in a terrine, crust or tin.

Pâté production technology comprises the following stages:

- **Preparation of raw materials:** Selection and cutting of meat, liver and fat;
- **Chopping and seasoning**: Mixing ingredients, spices and sometimes milk;
- **Assembly in terrine or tin:** The pastry is put into molds or suitable containers**;**
- **Slow cooking:** Low-temperature cooking to ensure a soft texture and good keeping qualities;
- **Packaging and cooling:** Canning or vacuum-packing, followed by cooling.

2.3. Cachir (or K-chir) production technology

Cachir is an emulsified sausage popular in North Africa, mainly composed of meat (often chicken or beef), fat, spices, and sometimes starch to obtain a homogenous, firm texture.

The production stages are as follows:

- **Preparation of raw materials:** Meat is minced very finely, mixed with fats and spices;
- **Emulsification**: Water and texture agents are added to create a fine paste;
- **Stuffing:** The paste is stuffed into artificial or natural casings;
- **Steaming:** Cooking at a controlled temperature to ensure a firm, even texture;
- **Cooling and packaging:** Rapid cooling, followed by vacuum-packing or slicing.

Figure 34 shows an example of pâté production.

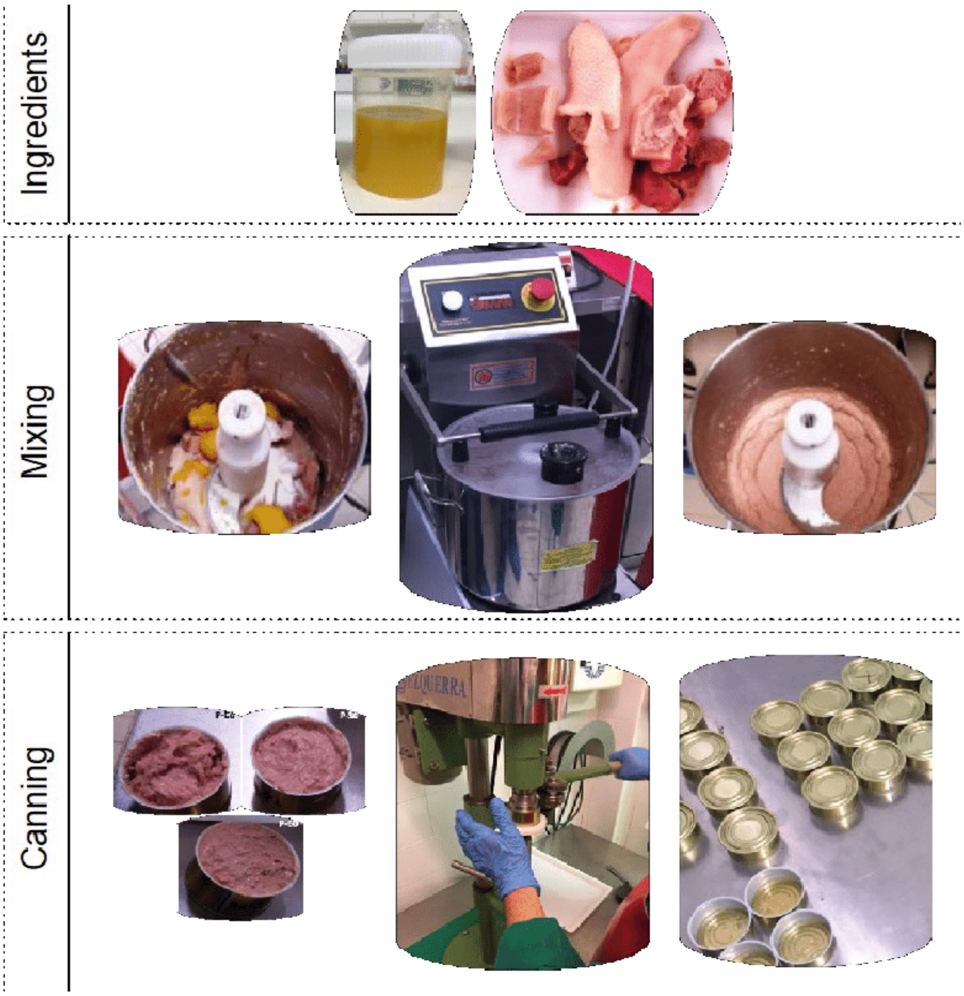


Figure 34: Main stages of pâté production (Martins *et al*., 2020).

VIII. CANNED FISH PRODUCTS (SARDINES, TUNA, etc.)

1. Definition and chemical composition of sardines

The most common sardine species are those belonging to the genera *Sardina* and *Sardinops*, which together with the genera *Engraulis* (anchovy), *Scomber* (mackerel) and *Trachurus* (horse mackerel) form the pelagic fish group that dominates temperate and subtropical waters.

In the North Atlantic, Mediterranean and Black Seas, on the Atlantic coasts from the Dogger-bank in the North Sea to the Saharan coast in Mauritania, it dominates the common sardine "*Sardina pilchardus* ".

The systematic position of the common sardine is as follows:

- **Phylum :** *Vertebrates*
- **Class:** *Osteichthyes*
- **Subclass:** *Actinopterygians*
- **Order:** *Clupeiformes*
- **Class:** *Clupeidae*
- **Family:** *Clupeidae*
- **Genus:** *Sardina*
- **Species:** *pilchardus*

The sardine has a shiny silvery belly and a bluish back. It is characterized by sessile scales that detach easily from the body, a striated operculum, and the last two rays of the anal fin are more elongated than the previous ones.

Sardines have a remarkable nutritional value, thanks to their high lipid content and ω-3 fatty acids (20-30% of total fatty acids). The fat content of sardines varies from 1.2 to 18.4 g per 100 g. Sardines are also one of the richest fish species in protein (around 20% of total fillet composition). Sardines are low in carbohydrates (0.1% by fresh weight), and contain vitamins, minerals and trace elements. In addition, sardines contain little sodium, but are rich in calcium, magnesium and potassium. With all these qualities, sardines are a low-calorie food (170 kcal per 100 g) that can be incorporated into most diets (Santos *et al.,* 2023).

2. Definition and chemical composition of tuna

The tuna is a large oceanic fish of the *Scombridae* family. Its body temperature is regulated by a special circulatory system that allows heat exchange.

The systematic position of the tuna can be defined as follows:

- **Kingdom**: *Animalia*
- **Phylum**: *Chordata*
- **Class**: *Actinopterygii*
- **Order**: *Scombriformes*
- **Family**: *Scombridae*
- **Genus**: *Thunnus*
- **Species**: There are several species of tuna,

- Atlantic or Mediterranean bluefin tuna, *Thunnus thynnus*. It measures up to 3 m in length and weighs 400 kg;
- Yellowfin tuna, *Thunnus albacares,* found in tropical and subtropical areas, smaller than bluefin tuna,
- Albacore tuna, *Thunnus alalunga*, found in tropical and subtropical areas of the Indian Ocean. Adults can reach 1.40 m in length and weigh 60 kg;
- Bigeye tuna, *Thunnus obesus*, with large eyes;
- Mignon tuna, *Thunnus tonggol* ;
- Pacific bluefin tuna, *Thunnus orientalis*.

Rich in protein, selenium, phosphorus and omega-3 fatty acids, tuna is a particularly nutritious fish (FAO, 2025).

3. Fish alterations

- **Aseptic muscle autolysis**

This is due to the activity of fish-specific enzymes, notably digestive enzymes: Pancreatin, pepsin, cathepsin, trypsin. These enzymes easily break down the viscera, then the muscles of the abdominal wall, which is why rapid evisceration is essential for successful processing. Lowering the temperature and acidifying the medium helps to prolong the latent period, i.e. before the body stiffens, thus improving the chances of preservation.

- **Bacterial degradation**

The mucus, gills and intestines are all compartments favorable to the development of bacteria. These are harmless as long as the fish is alive, but as soon as it dies, they multiply and invade the whole body through the gills from the abdominal cavity. In this way, they cause lysis of the fish's tissues.

- **Lipid oxidation**

Fish flesh contains lipids which, after death, come into contact with oxygen in the air, producing unpleasant odors as the flesh decomposes.

4. Steps in the manufacture of canned fish

Canned fish products of traditional importance include tuna, packed as steaks, chunks or flakes in oil or brine, sardines or sardine like fishes in oil or tomato sauce, pilchards in tomato sauce, pacific salmon, mackerel in a variety of sauces including tomato, mustard and curry, fish paste products, and smaller commodity items such as shrimps, mussels or crab. In recent years, there has been development in the range of products available. Canned salmon products are now available without skin and with the backbone removed as are skinless and boneless sardines.

Once received at the cannery, the fish undergoes the following stages (Bratt, 2013):

- **Brining**

Fresh fish enter the factory in one of two ways: either they are kept in a refrigerated chamber at a temperature of between 0 and 2°C for a maximum of two days, after which they enter the processing line, or they undergo brining. Brine is prepared in advance by dissolving salt in cold water at a concentration of 21%. After a few minutes' agitation, the fish are introduced into the brine at a rate of 1kg/4L of brine. To maintain a constant concentration gradient between the flesh and the brine, the latter is renewed every half-hour for the first six hours, then every two hours for the remainder of the salting period, until equilibrium is reached.

- **Cleaning**

Primary washing

The fish are cleaned by hand in a continuous stream of clean, trickling water.

Evisceration

Using a knife, the head and intestines of the fish are removed in a single stroke, without opening the belly.

Scaling

The scales are removed from the fish using a sharp knife.

Secondary washing

The fish are thoroughly rinsed with cold water, to remove all traces of waste remaining in the flesh after gutting and scaling.

- **Canning:** The washed fish are carefully placed in cans, which are arranged upside down to eliminate any excess wash water that has remained incorporated in the fish body.

- **Cooking:** The fish are cooked in a cooking vat (automatic direct steam cooker with vacuum cooking and cooling) at a temperature of between 80 and 100°C for 20 minutes.
- **Drying:** The fish are exposed to a flow of dry air at a temperature of 70°C generated by a drying radiator for 15 to 30 minutes.
- **Lubrication:** Each box is placed on a rolling mat and lubricated with vegetable oil.
- **Crimping**

Crimping is a semi-automatic operation which consists of joining the lid to the can using a crimping machine. This step ensures that the can is hermetically sealed and impervious to microbiological and atmospheric exchanges between the outside environment and the can.

- **Degreasing and autoclaving**

The cans of fish are placed inside a perforated tank, which is then transferred and impregnated by an electric elevator into another tank filled with degreasing agents, the purpose of which is to remove the layer of oil covering the outside of the can; this stage lasts approximately one minute.

The hermetically sealed cans are then placed in a sterilizer, or autoclave, for heat treatment at a temperature of over 100°C, under pressure. At the same time, the heat is used to cook the food. Sterilization schedules are very precise, and are established for each type of fish and packaging.

- **Packaging**

After rapid cooling (to avoid overcooking), the cans of fish are packed in cardboard boxes of varying capacity.

- **Storage and transport**

Fish boxes are kept in a storage room away from humidity and heat.

Canned fish should be transported in such a way as not to damage the containers.

Figure 35 illustrates the canned fish production line.

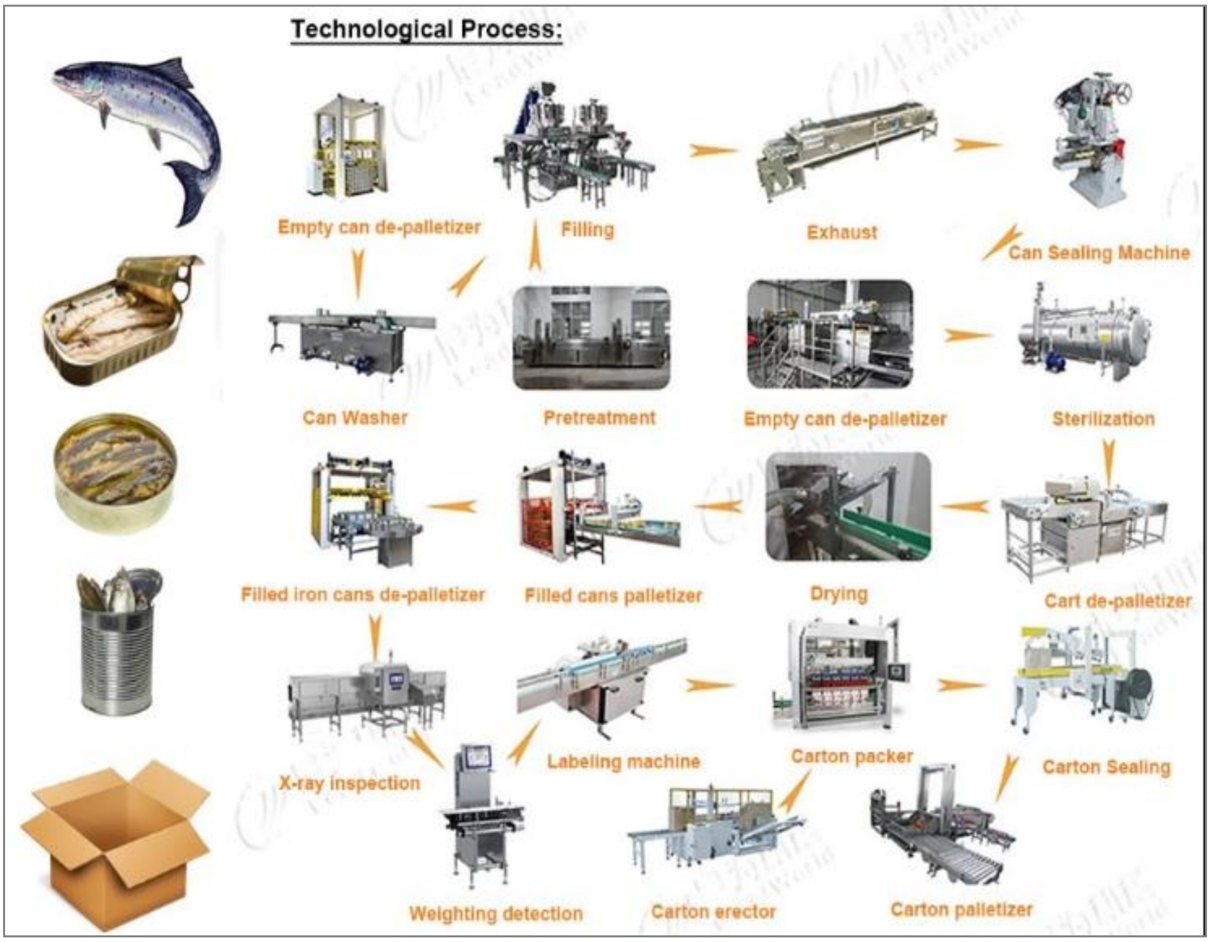


Figure 35: Canned fish production line (Source: https://shleadworld.en.made-in-china.com).

REFERENCES

Abecassis J., Cuq B., Boggini G., Namoune H. (2012). Other traditional durum-derived products. In Durum Wheat: Chemistry and Technology. 2nd ed.; Sissons M., Abecassis J., Marchylo B., Carcea M. AACC: St. Paul, MN, USA. pp. 177–199.

Akbar H. (2020). Maize: Production and use. BoD - Books on Demand. 156 p ISBN 1838802614, 9781838802615. [In French]

Alibekov R.S., Alibekova Z.I., Bakhtybekova A.R., Taip F.S., Urazbayeva K.A., Kobzhasarova Z.I. (2024). Review of the slaughter wastes and the meat by-products recycling opportunities. *Frontiers on Sustainable Food System.* 8:1410640.

Bathula S.R., Ravishankar B.V., Gullaya P.B.. (2018). Extraction of gluten from food material. *MOJ Proteomics & Bioinformatics*. 7 (3): 199–204.

Belk K. (2015). Does Muscle Tissue Contain Different Types of Protein. Champaign, IL: American Meat Science Association). Available at: https://meatscience.org/TheMeatWeEat/topics/freshmeat/article/2015/0/31/does-muscle-tissue-contain-different-types-of protein

Bhatkar N.S., Shirkole S., Brennan C., Thorat B.N. (2022). Pre-processed fruits as raw materials: Part I–different forms, process conditions and applications. *International Journal of Food Science & Technology*. 57(8):4945-4962.

Bisht B., Bhatnagar P., Gururani P., Kumar V., Tomar M.S., Sinhmar R., Rathi N., Kumar S. (2021). Food irradiation: Effect of ionizing and non-ionizing radiations on preservation of fruits and vegetables– a review. *Trends in Food Science & Technology*. 114: 372-385.

Boudreau A., Ménard G. (1992). Wheat: Fundamentals and Processing. Presses University Laval. 439 p. ISBN. 276377296X, 9782763772967. [In French]

Bratt L. (2013). Technical guide to fish canning. *GLOBEFISH Research Programme.* Vol. 111. Rome, FAO. 69p.

Brouns F., Hemery Y., Price R., Anson N.M. (2012). Wheat aleurone: Separation, composition, health aspects and potential food use. *Critical Reviews in Food Science and Nutrition*. 52(6):553-568.

Calín-Sánchez Á., Lipan L., Cano-Lamadrid M., Kharaghani A., Masztalerz K., Carbonell-Barrachina Á.A., Figiel A. (2020). Comparison of traditional and novel drying techniques and its effect on quality of fruits, vegetables and aromatic herbs. Foods. 9(9): 1261.

Codex Alimentarius. CODEX STAN 202-1995; Norme Codex pour le Couscous. *Codex Alimentarius Commission*: Rome, Italy, 1995.

Dang D.S., Bastarrachea L.J., Martini S., Matarneh S.K. (2021). Crystallization Behavior and Quality of Frozen Meat. *Foods*. 10: 2707.

Delcour J.A., Hoseney R.C. (2010). Principles of cereals science and technology. Third Edition. Cereals and Grains Association and Springer. 222 p. ISBN-13. 978-1891127632.

Devi P.B., Vijayabharathi R., Sathyabama S., Malleshi N.G., Priyadarisini V.B. (2014). Health benefits of finger millet (*Eleusine coracana L*.) polyphenols and dietary fiber: a review. *Journal of Food Science and Technology*. 51(6):1021-40.

Diane M.B., Somogyi L., H.S. Ramaswamy. (2004). Processing Fruits. Science and Technology, Second Edition. Taylor & Francis. 841 p.

Dikovsky D. (2024). Addressing the structural sophistication of meat via plant-based tissue engineering. *Frontier of Soft Matter*. 4:1343906.

Fitz J.I., Kuipers B. (2003). Preservation of fruit and vegetables. 4th Rev. Ed. Agromisa Foundation Wageningen, Pays-Bas. ISBN: 978-90-77073-30-8.

FAO - Food and Agriculture Organization. (2025). Biological characteristics of tuna. Available at: https://www.fao.org/fishery/en/topic/16082/en

Gagaoua M., Boudechicha H.R. (2018). Ethnic meat products of the North African and Mediterranean countries: An overview. *Journal of Ethnic Foods*. 5(2): 83-98.

Ganvit J., Harsh S. Dinesh H., Kuldeep K., Lautre R. (2023). Recent trends in vegetable science: Unleashing the future direction. pp. 300–313. Elite Publishing House. ISBN : 978-93-58992-62-5.

Godon D., Loisel W., Multon J.L.. (1998). Practical Analysis Guide for the Cereal Industry. 2e éd. Technique & Documentation. 818 p. [In French]

Gomez-Lopez V.M., Pataro G., Tiwari B., Gozzi M., Meirelles M., Wang S., Morata A. (2021). Guidelines on reporting treatment conditions for emerging technologies in food processing. *Critical Reviews in Food Science and Nutrition*. 62(21):5925-5949.

Hammami R., Barbar R., Laurent M., Cuq B. (2022). Durum Wheat Couscous Grains: An ethnic mediterranean food at the interface of traditional domestic preparation and industrial manufacturing. *Foods*. 11: 902.

Hathi H.S., Ganvit J.M., Zankat S.B., Malviya A.V., Patel N.K. (2023). Vegetable canning. In Ganvit J.M., Hathi H.S., Kuldeep D.K., Lautre R. (Eds.), *Recent trends in vegetable science: Unleashing the future direction*. Elite Publishing House. pp. 300–313.

Ivanović S., Pavlović I., Pisinov B. (2016). The quality of goat meat and it's impact on human health. *Biotechnology in Animal Husbandry*. 32(2): 111-122.

Kill R.C., Turnbull K. (2000). Pasta and semolina technology. Blackwell Science Ltd. ISBN: 9780632053490 . 225 p.

Kłosok K., Welc R., Fornal E., Nawrocka A. (2021). Effects of physical and chemical factors on the structure of gluten, gliadins and glutenins as studied with spectroscopic methods. *Molecules*. 26(2): 508.

Kučerová J. (2015). Technology of cereals. Mendel University in Brno. Faculty of Agronomy. ISBN 978-80-7509-343-1

Kumar P., Verma A.K., Umaraw P., Mehta N., Sazili A.Q. (2022). Chapter 9: Processing and preparation of slaughtered poultry. In: Seid Mahdi Jafari; Postharvest and postmortem processing of raw food materials. Woodhead Publishing. pp: 281-314. ISBN 9780128185728.

Martins A.J., Lorenzo J.M., Franco D., Pateiro M., Domínguez R., Munekata P.E.S., Pastrana L.M., Vicente A.A., Cunha R.L., Cerqueira M.A. (2020). Characterization of enriched meat-based pâté manufactured with oleogels as fat substitutes. *Gels*. 6(2):17.

Nwankwo S.C., Osinachi U.F., James M.T., Chigozie O.F., Dereje B., Irene C.E. (2021). Technological advancements in the drying of fruits and vegetables: A review. *African Journal of Food Science*. 15(12): 367-379.

Omidvar R., Sipos M., Farzad R. (2024). Fish fillet: White versus red, structure and nutritional composition. IFAS Extension. University of Florida. https://doi.org/10.32473/edis-FS454-2024

Papageorgiou M., Skendi A. (2018). Chapter I: Introduction to cereal processing and by-products. In: Sustainable recovery and reutilization of cereal processing by-products. Alexander Technological Educational Institute of Thessaloniki (ATEITh), Thessaloniki, Greece. 25p.

Pașca C., Coroian A., Socaci S. (2018). Risks and Benefits of Food Additives – Review. *Bulletin Of University Of Agricultural Sciences And Veterinary Medicine Cluj-Napoca. Animal Science And Biotechnologies*. 75(2): 71.

Patel P., Butani K., Kumar A., Singh S., Prajapati B.G. (2023). Effects of Fermented Food Consumption on Non-Communicable Diseases. *Foods*. 12: 687.

Petrovic Z., Djordjevic V., MilicevicIvan D., Nastasijevic I., Parunovic N. (2015). Meat production and consumption: environmental consequences. *Procedia Food Science.* 5: 235-238.

Reynolds M.P., Braun H.J. (2022). Wheat improvement: Food security in a changing climate. Springer. 629 p. ISBN : 978-3-030-90672-6.

Ruiz T., Rondet E., Cuq B. (2014). Couscous Grain: From handicraft to fractal growth." In *Culinary Sciences*. Lavelle C., Ed.; Échelles Collection, Belin: Paris, France. pp. 28–51. [In French]

Sade L., Kweon M., Levine H. (2020). Exploration of the functionality of sugars in cake-baking, and effects on cake quality. Critical Reviews in Food Science and Nutrition. 61(2): 283-311.

Santos H.O., May T.L., Bueno A.A. (2023). Eating more sardines instead of fish oil supplementation: Beyond omega-3 polyunsaturated fatty acids, a matrix of nutrients with cardiovascular benefits. *Frontier Nutrition.* 10:1107475.

Schumann M., Holm J., Brinker A. (2022). Effects of feeding an all-plant diet on rainbow trout performance and solid waste characteristics. *Aquaculture Nutrition*. 2022:1-11.

Singh R.P, Cross H.R. (2022). Livestock slaughter procedures in meat processing. Encyclopedia Britannica. Available at: https://www.britannica.com/technology/meat-processing/Livestock slaughter-procedures

Sinhamahapatra M. (2022). Environmental issues in meat industry and their solutions- A review. *Indian Journal of Animal Health*. 61(2)- Special Issue: 55-66.

Slavin J.L., Lloyd B. (2012). Health benefits of fruits and vegetables. *Advances in Nutrition*. 3(4): 506–516.

Soni A., Brightwell G. (2022). Effect of hurdle approaches using conventional and moderate thermal processing technologies for microbial inactivation in fruit and vegetable products. *Foods*. 11: 1811.

Srivastava R.P., Sanjeev K. (1998). Fruit and vegetable preservation (Principles & Practical). International Book Distributing Co., Lucknow.

Stanley C. (2015). Technology of bread making. 3rd Edition. Springer Cham. XX, 408p. ISBN.978-3-319-14686-7.

Tanase T. (2013). Yield in milling. Constanta-Romania. 16p.

Ratti C. (2008). Advances in food dehydration. CRC Press. 467 p. ISBN. 9781420052534, 1420052535.

Reeves T.G., Graeme T., Gordon R. (2015). Save and grow in practice: Maize, rice, wheat. FAO. 124 p. ISBN. 978-92-5-108519-6

Verma L.R., Joshi V.K. (2000). Post harvest technology of fruits and vegetables. Vol. 2, Indus Publishing Company, New Delhi. 823 p.

Wrigley C.W., Taylor J.R.N. (2023). Chapter 1: Origin, evolution, production, and utilization of cereals, Editor(s): Peter R. Shewry, Hamit Koksel, John R.N. Taylor, ICC Handbook of 21st Century cereal science and technology. Academic Press. pp: 1-15, ISBN 9780323952958

Wrigly C., Batey I., Miskelly D. (2017). Cereal grains: Assessing and managing quality. Second Edition. A volume in Woodhead Publishing Series in Food Science, Technology and Nutrition. 788 p.

Zhang R., Ma S., Li L., Zhang M., Tian S., Wang D., Liu K., Liu H., Zhu W., Wang X. (2021). Comprehensive utilization of corn starch processing by-products: A review. *Grain & Oil Science and Technology*. https://doi.org/10.1016/j.gaost.2021.08.003

Zhao P., Ndayambaje J.P., Liu X., Xia X. (2022). Microbial spoilage of fruits: A Review on causes and prevention methods. *Food Reviews International*. 38(sup1): 225-246.