POST GRADUATE DIPLOMA
IN
BAKERY SCIENCE AND TECHNOLOGY

PGDBST – 01

WHEAT GRAIN STRUCTURE, QUALITY AND MILLING

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UNIT-1 CLASSIFICATION AND STRUCTURE OF WHEAT GRAIN

STRUCTURE

OBJECTIVES

After studying this unit you should be able to:

- Classify wheat and describe its characteristics and uses.
- Explain the structure of wheat.
- Know the chemical composition of wheat grain.
- Understand the factors affecting grain size.
- Describe the factors responsible for wheat hardness/softness.

1.1. INTRODUCTION

1.1.1. ORIGIN

Wheat was one of the first of the grains domesticated by humans. Its cultivation began in the Neolithic period. Bread wheat is known to have been grown in the Nile valley by 5000 BC, and its apparently later cultivation in other regions (e.g., the Indus and Euphrates valleys by 4000 BC, China by 2500 BC, and England by 2000 BC) indicates that it spread from Mediterranean centers of domestication. The civilizations of West Asia and of the European peoples have been largely based on wheat. Since agriculture began, wheat has been the chief source of bread for Europe and the Middle East. It was introduced into Mexico by the Spaniards about 1520 AD and into Virginia by English colonists early in the 17th century.

Wheat is cultivated for food since prehistoric times by the peoples of the temperate zones and now the most important grain crop of those regions. The great wheat-producing countries of the world are the United States, China, and Russia, India, W Europe, Canada, Argentina, and Australia. High-yield wheat, one of the grains resulting from the Green Revolution, requires optimal growth conditions, e.g., adequate irrigation and high concentrations of fertilizer.

1.1.2. CLASSIFICATION OF WHEAT

Wheat is a member of the family Poaceae (formerly Gramineae). It makes up the genus *Triticum*. It is a tall, annual plant attaining an average height of 1.2 m (4 ft). The leaves, which resemble those of other grasses, appear early and are followed by slender stalks terminating in spikes, or so-called ears, of grain.

Species of wheat are classified according to the number of chromosomes found in the vegetative cell. There are over 20 species of wheat, differing in their basic number of chromosomes (diplo-, tetra-, and hexaploid), and several thousand varieties. The most economically significant species are the ordinary wheat *Triticum aestivum* subsp. *vulgare* (hexaploid) and the hard wheat *Triticum durum* (tetraploid).

Triticum aestivum: the classes belonging to this species are hard red winter, hard red spring, soft red winter, soft and hard white. Kernel hardness in protein content vary widely within this species. Common wheat may be winter or spring growing habit and may have either red or white kernels. Its flour is superior to that of all other species for the production of leavened bread. Climatic and soil conditions also have a marked influence on the suitability of common wheat for specific types of flour.

Triticum compactum (club wheat): Both winter and spring varieties are grown. The kernels have a soft texture and low protein content and is not well suited for bread flour but is excellent for certain types of cakes and pastries flour.

Triticum durum: It has spring growing habit. Principle production among this variety is of amber (white) varieties. The kernels are hard in texture and high in protein content. Most of this crop is used for the production of semolina or durum flour for the pasta productions because the qualities of durum gluten make it particularly desirable for this use.

1.1.3. PRODUCTION

The global area of wheat cultivation covers a total of about 240 x 10^6 ha, and approximately 90% of that is occupied by *Triticum aestivum* which has the greatest number of crop-yielding varieties of starchy grains. There are numerous varieties of *Triticum durum* cultivated in continental climate zones and covering approximately 10% of the total area.

Major wheat producers in world (FAO, 1999)

	Area Harvested, ha	Production, Mt	Avg. Yield, Mt/ha
World	**212,254,522**	**585,466,595**	**2.76**
China	28,855,019	113,880,088	3.95
India	27,398,000	70,778,496	2.58
USA	21,781,000	62,569,000	2.87
Russian Federation	19,755,200	30,995,150	1.57
Australia	12,338,000	25,012,000	2.03
Canada	10,366,700	26,900,000	2.59
Kazakhstan	8,736,300	11,241,900	1.29
Turkey	8,650,000	16,500,000	1.91
Pakistan	8,229,900	17,857,600	2.17
Argentina	6,072,000	15,100,000	2.49
Ukraine	5,931,600	13,585,300	2.29
France	5,115,195	37,050,000	7.24
Iran, Islamic Rep of	4,739,058	8,673,197	1.83
Morocco	2,690,600	2,153,540	0.80
Germany	2,609,444	19,615,366	7.52
Poland	2,582,969	9,051,339	3.50
Spain	2,422,400	5,083,800	2.10
Italy	2,387,266	7,742,782	3.24
Afghanistan	2,027,000	2,499,000	1.23
United Kingdom	1,847,000	14,870,000	8.05

1.2. GRAIN SIZE AND MORPHOLOGY

The wheat grain or the wheat kernel is one seeded fruit, called caryopsis. A wheat kernel is about 5-8 mm in length and 2.5-4.5 mm in width. The wheat kernel has a longitudinal crease that extends almost to the center of the kernel. The existence of the crease makes much of handling of the grain more difficult. It has been suggested that one way to improve wheat would be to eliminate the longitudinal crease. The wheat kernel is somewhat thicker toward the end where the embryo is located. At the opposite end hairs of brush are located.

The dorsal side of the wheat grain can be oval, ovate, or elliptical, with a cluster of long or short brush hairs at the apex, and the oval or circular embryo at the bottom. The dorsal profile can be ridged or smooth, the ventral part of the profile having a prominent radicle. The ventral side has a deep groove or crease along the entire longitudinal axis. The shape of the groove is a characteristic feature of some species and varieties.

The grain coat is made up of the fruit and seed coat, adhering directly to the aleurone layers of translucent cells, strongly lignified, elongated in shape and encrusted with mineral substances and of a layer of perpendicular and tubular cells. The seed coat consists of a compact cell layer and pigment strand, providing the grain with its characteristic coloring.

The aleurone layer made up of large thick walled cells filled with functional proteins and nutritional components, encloses the endosperm, and disappears around the embryo.

The endosperm consists of large, thin-walled cells, filled mainly with starch and protein. In the subaleurone area, especially on the dorsal side of the grain, the dominant cells are elongated in the direction of the endosperm center. Cells within the endosperm are less regular in shape. Starch grains are enclosed in the thin layer of adherent protein and located within a protein matrix which fills the individual cells of the endosperm to varying degrees. The highest content of protein is observed in the cells of the subaleurone layer of the endosperm. The closer to the center of the grain, the lower the protein content.

1.2.1. SOURCES OF GRAIN SIZE VARIATIONS

There can be numerous factors including genetic, production, and agronomic practices responsible for causing variation in grain size. Grain pinching is due to environmental and crop-management stresses, although some varieties show a greater tendency than others to produce pinched grain. Screenings are grains that are so small, pinched or cracked that they pass through a standard sieve and lead to reduced price. The following factors are known to affect grain size, pinching and screenings but there is much that we do not know.

Immaturity at harvest may result in shriveled and green kernels, thus reduces the size of kernel, yield and quality of the flour produce.

Carbohydrate supply: A major factor in determining average seed size is the supply of carbohydrate available to fill the number of grains set. When more grains are set, there is less carbohydrate to fill each grain, so average size is reduced. Even when there is adequate soil water during grain filling there is usually some reduction in grain size. Drought during grain filling leads to a greater reduction in average grain size and an increase in screenings.

Most wheat varieties released over the past few decades have relatively small grains. When grain number is increased with nitrogen fertiliser, the average grain weight is decreased and the chance of screenings is increased.

Haying-off: The process of haying off is when excessive nitrogen leads to decreased yield with an increase in the percentage of pinched grain. It was widely believed that the main reason was insufficient soil water after flowering to fill the grain, because soil water had been depleted to produce extra vegetation. Recent research suggests that lack of soil water after flowering is probably a secondary cause of haying off. The main reason is that high-N status leads to reduced soluble carbohydrate stored in the stems at the time of flowering and so less reserves for grain filling.

Variation within the ear: There is variation in grain size within the ear even in good growing conditions. Typically the outside grains within a spikelet are smaller than those closer to the centre. There is also some variation along the length of the ear, with grains near the top being smaller than the others, but the vertical variation is not as great as the sideways variation. The reduced size in both the tip and side spikelets is probably due to the poorer 'plumbing' to grains that are furthest from the base of the ear. The screenings are mostly the 3rd or 4th grains on the spikelet.

High temperature: High temperature in the days before flowering leads to a reduced cell number in the ovules, and hence a reduced potential grain size. High temperatures after flowering also lead to reduced grain size. Generally high temperatures reduce the duration of grain filling and hence average grain size.

Loss of leaf area: Leaf diseases such as yellow leaf spot have been a major cause of small grain.

Improperly adjusted threshing equipment may further reduce the kernel size by breaking them, leading to a yield loss to the mills. Rapid artificial drying may cause minor fissures in grain, which result in excessive breakage during subsequent handling.

1.2.2. RELATIONSHIP OF GRAIN SIZE WITH ENDOSPERM AND PROTEIN CONTENT

Broadly speaking, grain size is positively co-related with the endosperm content and negatively with protein content of the wheat kernel.

A balanced source sink relationship determines translocation of photosynthates from leaves and stems reserves to grain. Deposition of photosynthate also determine the grain size. There exists genetic variability in wheat for post anthesis, translocation of photosynthates, per day accumulation of photosynthates and duration of grain development. This leads to variation in grain quality.

Grain size determines the wheat quality especially protein quality. In case of poor endosperm development, although grain protein content (%) increases due to relatively higher membrane proteins, but overall protein quality for end use purpose reduces. Appropriate development of endosperm and embryo is therefore important. Gluten content of the protein including glutenin and gliadin determines end use quality in wheat.

1.2.3. TECHNIQUES USED TO STUDY THE STRUCTURE OF WHEAT GRAIN

Three main branches of microscopy- light, scanning electron and transmission electron microscopy are successfully used to study the structure and composition of wheat and wheat-based products. The objectives of the studies vary from gaining fundamental information on the accumulation of cellular constituents in the developing wheat grain to providing information which can improve our understanding of differences in processing ability or overall quality of wheat and wheat-based products. Microscopical observations should always be linked to other technological, chemical or physical data.

Light microscopy (LM) and transmission electron microscopy (TEM) have the advantage that many staining techniques have been developed to assist recognition of constituents and provide data on chemical composition. However, these techniques generally require the use of solvents during sample preparation and these can give rise to artifacts (swelling, shrinking or leaching of soluble material). Few specific stains are available for use in scanning electron microscopy (SEM), and constituents are generally identified by their shape or location. The advantage of SEM is that, in some cases, sample preparation artifacts can be minimized.

Light Microscopy (LM)

The main stages in the preparation of samples for examination by LM are fixation, embedding, sectioning and staining, The aims of fixation are to preserve samples from attack by enzymes or microorganisms, render some constituents insoluble, and strengthen the sample to improve structural integrity during sectioning. The most commonly used fixative is aqueous, buffered glutaraldehyde but specialized fixatives have been developed for specific applications (e.g. fixation of lipid-rich samples). Baked samples, which have been heat-fixed, may not require chemical fixation. Embedding is used to provide additional support during sectioning, and commonly used embedding media are water and aqueous gums for cryostat microtomy, synthetic resins or special waxes. Resins are generally used where thinner sections are required and are cut using glass knives. Cryostat microtomy and sectioning of wax-embedded samples are carried out using steel knives. Sections, supported on glass slides, are then usually stained prior to mounting and examination.

The stains commonly used for examination with transmitted bright-field illumination are listed in Table 1 together with their substrates. Fluorescence microscopy has been widely used and may rely on auto fluorescence or application of fluorescent dyes. The use of fluorescent dyes coupled to specific antibodies or lectins is rapidly expanding and several are listed in Table 2. Other coupled antibody techniques have developed whereby coloured reaction products are produced. Polarized light can be used to study the extent of starch gelatinization or to provide detail of cell wall structure.

Table 1. List of stains commonly used for bright-field microscopy of wheat and wheat products

Substrate	Stain	Comments
Starch	Periodic acid-Schiff (PAS) reaction	Covalent, irreversible; may requir aldehyde blockade if aldehyde fixed
	Iodine or potassium iodide	Temporary stain only. Amylos stained blueblack; amylopectin staine red-brown
Protein	Fast green, Ponceau 2R and other anioni dyes	Ionic, reversible Intensity influence b pH and differentiation
	Coupled antibody or lectin stains	Potentially more specific for selecte protein
Lipid	Sudan IV or oil red O in 70% ethanol	Temporary stain only; intensit influence by differentiation
Cell walls	Toluidine blue O	Metachromatic stain. Lignified wall stained green: testa stained purple other cellulosic walls stained blue
	Zinc-chlor-iodide	Temporary stain only; Lignified

Yeast	Methylene blue, pH 4.6	Yeast stained blue: gluten unstained owing to low pH

Table 2. List of stains and conditions commonly used for fluorescent microscopy of wheat and wheat products

Substrate	Stain	Comments
Starch	Periodic acid-Schiff (PAS) reaction	More sensitive than bright-field PAS for thin sections
Protein	Acid fuchsin	More sensitive than bright-field stain for thin sections
	Coupled antibody or lectin	Potentially more specific
Lipid	Aqueous phosphine 3R	As aqueous solution, lipid distribution less likely to be altered compared to Sudan dyes
Cell Walls	Autofluorescence	Walls containing lignin or phenolic acids autofluoresce
	Coupled lectin	Specific for selected glycoprotein

Scanning Electron Microscopy

The scanning electron microscope has a greater depth of focus than the light microscope and therefore it is not necessary to section samples prior to examination. Samples are normally coated with a thin layer of an electrically conduction material, usually gold, platinum or carbon, prior to examination. Samples of dry wheat (<12% moisture) or similar products only require air-drying over a desiccant prior to coating. Samples, which contain more moisture, may be rapidly frozen prior to dehydration using freeze-drying or critical point drying. The development of cold stages in SEM has obviated the need for drying and this technique, together with freeze-etching, has been successfully used to examine those cereal foods in which moisture is high and forms an integral part of the structure.

Transmission Electron Microscopy

Samples for TEM require fixation and thin sectioning. Initial fixation is usually with glutaraldehyde followed by fixation with osmium tetroxide. The fixed tissue blocks are rinsed, dehydrated and embedded with a resin prior to sectioning. Heavy metal salts are used to stain the sections and enhance contrast; more recently, antibody staining has been developed whereby the antigenic sites are located at TEM level by the presence of colloidal gold particles, which are coupled to the antibodies.

Image Analysis and Other Quantitative Techniques

The value of all the above work has been enhanced by the application of stereology techniques and, more recently, by automatic image analysis. Microspectro-fluorimetry has been used to study composition of bran layers and to relate this information to the quantification of bran components in flour streams.

1.3. PROTEIN QUALITY

Proteins attract special attention because they are basic factors of wheat quality and the most important component in human’s diet.

Essential amino acids, as lysine, methionine, arginine, histidine, leucine, tryptophan etc. are produced only in plant cells, but they are of great importance for nutrition of animals and humans who are not capable of synthesizing these amino acids. Simple proteins are building materials in human body, but as storage materials they can be found in plant seeds. Glutelin is build of essential amino acids and it can be found in wheat, maize etc. Prolamins of wheat i.e. gliadins lack essential amino acids in their molecule. Compound proteins in their molecule except simple protein consists and prosthetic group a non-protein moiety, as glycoproteins, lipoproteins, cromoproteins and nucleoproteins, which are of great significance.

Osborn's classification of protein is based on their solubility and it is widely accepted and later complemented, because each of the four fractions: albumin (soluble in water), globulin (soluble in neutral salts), prolamin (soluble in alcohol) and glutenin (soluble in dilute bases) is a mixture of heterogeneous proteins. Glutenin and gliadin form a compound called gluten, which is important in dough and is 10-15% in wheat grain.

Storage proteins in endosperm of wheat grain represent over 80% of the whole quantity of proteins in grain. Approximately 50% of storage proteins are soluble in 70% ethanol on normal temperature and they are classified as gliadins, whereas proteins not soluble in ethanol are classified as glutenins.

1.4. ∝-AMYLASE ACTIVITY

Alpha-amylase enzyme is present in the embryo or germ of sound wheat kernels, when germination begins the embryo and layers surrounding the starchy endosperm produce the enzyme at an accelerating rate. A severely sprout-damaged kernel contains many thousands of times the amounts of enzyme present in kernels that are in the early stages of germination. Because of this, a wheat sample containing very low levels of severely sprouted kernels may exhibit higher amylase activity. Alpha-amylase converts starch into sugars, and breaks down the starch granules in wheat flour when mixed with water to make bread dough.

The action of alpha-amylase affects many bread making properties of flour made from sprout-damaged wheat. The sprout-damaged flour holds less water when mixed and the dough absorbs less water during baking. The baker must use more flour to make the same number of loaves of bread, an important cost factor. The enzyme also affects gas retention, dough handling and bread texture. Too much alpha-amylase activity causes wet, sticky dough that is hard to handle in a commercial bakery. The loaf may have large open holes and the crumb texture is gummy. The gummy bread is difficult to slice and builds up on slicer blades. The loaves are often deformed, hard to package and unattractive to customers. For these reasons, many buyers place strict limits on the amylase activity in wheat they buy. The internationally accepted measure of alpha-amylase activity is known as the Falling Number.

Falling Number: The Falling Number (FN) is the internationally standardized and most popular method for determining amylase levels in wheat. The method is based on the enzyme's ability to break down starch and liquefy a warm, thickening mixture of ground wheat or flour. The greater the enzyme activity, the faster the viscous solution is thinned.

The FN instrument records the time in seconds required to warm and stir the mixture 60 seconds-and the time it takes a plunger to fall through the thickening mixture. The more enzyme activity, the faster the mixture liquefies or thins, and shorter the time it takes the plunger to drop a measured distance. Falling Number readings range from the minimum 60 seconds for a very damaged sample to over 400 seconds for a very sound sample. The minimum FN generally accepted is 250 seconds. The relationship between FN and sprout-damaged kernels is unpredictable.

1.5. PHYSICO-CHEMICAL BASIS OF WHEAT GRAIN HARDNESS OR SOFTNESS

Hardness is arguably one of the most important factors in assessing the quality of wheat. It is a characteristic often used in milling industry to classify wheat according to desirability of their milling and bread making properties. Wheat hardness has no universally accepted definition but the term has come to several different meanings such as:

Hard wheat is one that can be milled to produce flour with high levels of starch damage desirable for bread production, and that grinds to give relatively angular particles that flow easily and are easy to handle.

Hardness is defined as a mechanical property of the individual wheat grain or resistance to deformation or crush.

Hardness is controlled by a single major gene located on the short arm of chromosome 5D.

The importance of wheat grain hardness lies in the fact that it determines the end use of the wheat that is the suitability of the flour milled from that wheat for various purposes. It affects the force required to fracture the grain, manner of fracture, resultant size of fragments, and sifting behavior of the flour. The following table represents the end use of grain according to its hardness related to protein content.

Classification of wheat grain and their end use

Type of Wheat	Protein (%)	Uses

T. aestivum	14-16	Bread
T. durum	12-14	Pasta products
T. compactum	7-12	Biscuits

Theories of hardness

Starch granule-protein matrix adhesion:

Hardness in wheat is related to the degree of adhesion between starch and protein. It may be the water-soluble protein concentrated at the starch protein interface, which is responsible for the adhesion of starch and protein. Soft wheat starch contains water soluble protein (friabilin) located on the surface of the starch granule. A protein band of apparent molecular weight of 15 kDa inhibits starch protein adhesion and produces a soft texture. Starch granules are more easily separated from their protein matrix in soft wheat endosperm and that hard wheat starch granules have generally high protein adhering than soft wheat starch.

Porosity of endosperm or continuity of protein matrix:

An alternative theory is that wheat endosperm hardness causes the porosity of endosperm. Voids in porous material can concentrate stress and cause a reduction in mechanical strength. In some cases such pores may be associated with interfaces of planes of weakness between particle and matrix in particulate composite materials. Such porosity is also being observed in wheat endosperm and proposed as a mechanism in determining its hardness. Vitreous hard kernels had higher density than soft kernels and that low density was attributed to the presence of air spaces or voids within the endosperm. The degree of compactness of protein matrix also affect hardness as hard wheat has a continuous protein matrix which physically entraps the starch granules (result in difficult separation of starch from protein) than that of soft wheat containing many air spaces.

Effect of Hardness on Conditioning:

1. Rate of movement of moisture into grain (is rapid in soft, mealy grains)
2. Moisture level tolerance with regard to flour yield (is more in hard grains)

Effect of hardness in milling:

1. Cleanliness of separation of endosperm from bran (bran clean up is better in hard grains)
2. Moisture level tolerance (is more in hard wheat)
3. Reduction of endosperm (is better in hard variety)
4. Sieving behavior of flour (is better in hard variety)

1.6. STRUCTURAL COMPONENTS OF WHEAT GRAIN

The main morphological components of the grain are the bran, endosperm and wheat embryo/germ. The outermost layer bran layer (epidermis and hypodermis) together constitute the outer pericarp. Adjacent to the outer pericarp is the inner pericarp composed of several compressed cell layers (formerly the parenchyma cells of the pericarp), a single layer of cross cells and tube cells. The latter do not form a continuous layer and are only recognizable in the mid-dorsal region of mature kernels. The next layer inwards is the seed coat or testa and it is this layer that is strongly pigmented in red wheat. Tightly bound to the internal surface of the seed coat is the nucellar layer. All the preceding tissues are derived from maternal tissue, but the aleurone and endosperm are formed after fertilization and contain genetic material derived from both parents.

Although the aleurone layer is anatomically a part of the endosperm, the miller regards the aleurone as the innermost layer of the bran. The majority of mineral matter located in bran is found in the aleurone layer, which also contains one third of the grain's thiamin content. In wheat there is a single layer of aleurone cells which surrounds all of the starchy endosperm except for that adjacent to the scutellum. The aleurone cells can vary in thickness from 30-70 μm within a single kernel and have thick (6-8 μm), double layered cellulosic walls. The cytoplasm of the cells contain many small (3-4 μm), round aleurone granules surrounded by lipid droplets. The aleurone granules are proteineous and rich in basic amino acids. Each granule contains two types of inclusions ; type one contains phytin and type two contains protein, carbohydrate and bound nicotinic acid ,which is largely unavailable for human nutrition. The phytin granules are main source of mineral matter in the aleurone and hence the degree of aleurone (or bran) contamination of flour is frequently evaluated by an ash analysis. The wheat germ is composed of two components, the embryo and scutelum, the outline of the germ can be detected under the modified bran layers of the dorsal surface at the proximal end of the grain. The scutelum is adjacent to the endosperm and contains the remaining two thirds of the grain's thiamin content. At the distal end of the grain are a number of hair (trichomes) which form a large part of the dust created during grain handling.

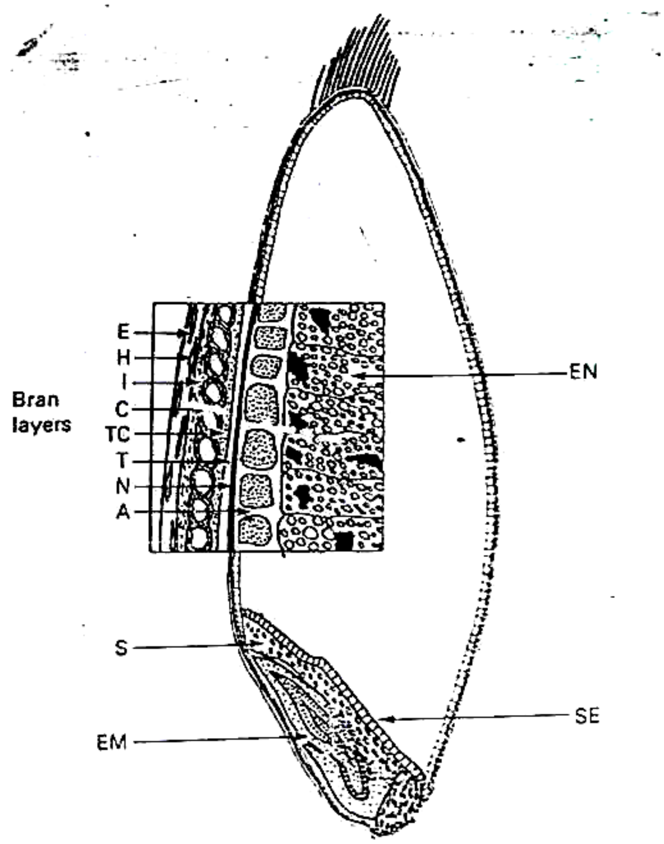

Fig. 1 Diagram of the main morphological components of the wheat grain. E, epidermis; H, hypodermis; I, inner pericarp; C, cross cells; TC, tube cells; T, testa; N, nucellar layer; A, aleurone layer; EN, starchy endosperm; SE, scutellar epithelium; S, scutellum; EM, embryo.

The main constituents of endosperm cells are starch granules and proteins, but small lipid droplets can be seen associated with the protein. The subaleurone cells are last to be initiated during grain filling and tend to be smaller then the other endosperm cells (60 μm in dia and 20-60 μm radially) and have thicker cell walls (8 μm). Below these cells are prismatic cells which are longer radially (150-200 μm). The central endosperm cells are first to be formed and are considerably larger (150 μm in dia) and have thinner walls (2 μm). The protein content of subaleurone cells is greater then in central endosperm, and in high protein kernels the main constituent of these cells is protein, with a few intermediate sized (10-15 μm) starch granules located at the periphery of the cell. The starch granule in wheat are frequently classified into two size groups: large, elliptically shaped A granules (30-40 μm in dia) and small, round B granules (<10 μm in dia) which are form later in grain filling process.

1.7 CHEMICAL COMPOSITION OF WHEAT KERNEL

The chemical composition of wheat grain and of its anatomical parts is determined by genetic and ecological factors and by the physical and chemical effects acting on the grain during its storage and processing.

The primary quantitative component of wheat is starch. Apart from starch the grain and especially the grain coat, the aleurone layer and the embryo, contain other carbohydrates, such as cellulose, hemicelluloses (pentosans), and sugars. Pentosans although their content is low (2-3%) are important owing to their water absorbing capacity i.e. 10 times their mass. In combination with other hemicelluloses they form the basic structure of endosperm cell walls. The following tables give an overview of different chemical components of whole wheat grain and its different fractions.

Chemical composition of wheat kernel parts (% Dry-Weight Basis)

Chemical components	Whole grain	Grain coat with endosperm	Embryo	Endosperm
Proteins %	10-12	23-33	36-42	9-14

Carbohydrates %				
Starch	60-70	0	0	78-84
Sugars	3.0-6.0	3.0-5.0	22-28	3.0-4.0
Pentosans	6.0-9.5	30-40	9-11	2.5-3.0
Cellulose	2.5-3.3	12-20	3-5	0.13-0.18
Fats	2.0-2.5	7.0-8.5	12-16	0.5-0.7
Minerals	1.4-2.3	9-11	5-6	0.3-0.5

Chemical Composition (%) of Endosperm, Bran and Germ (on 14% moisture basis)

Components	Whole wheat	Endosperm	Germ	Aleurone	Bran
Protein	8.2-12.1	5.8-16.2	24.3-31.1	18.4-24.3	2.85-7.60
Ash	1.8	0.5-0.8	3.65-9.47	11.1-17.2	1.7-5.1
Fiber	9.0	1.4	8.6	43.0	17.1-73.3
Lipids	1.8	1.6-2.2	5.05-18.8	6.0-9.89	0.0-1.03
Starch	59.2	63.4-72.6	0.0	0.0	0.0

1.8.SUMMARY

Wheat is the most important grain crop of temperate regions. It is member of family Poaceae and most significant species are *Triticum aestivum* subsp. vulgare which constitutes 90% of whole production and used mainly for bread .Remaining production is of *T. durum* and. *T. compactum* used for production of pasta; cakes and pastries respectively. Morphologically, wheat grain can be divided into 3 parts i.e. bran, endosperm and germ. Bran is removed during milling. Chemically, whole wheat grain consists of starch (60-70%), protein (10-12%) and minerals (1.4-2.3%), pentosans (6.0-9.5%), cellulose (2.5-3.3%), sugars and fats. Pentosans although their content is low (2-3% in endosperm) are important owing to their water absorbing capacity. Proteins of wheat are classified into albumin, globulin, prolamin and glutenin as per their solubility. Alpha amylase enzyme is present in embryo or germ of sound wheat kernels and it is a critical component for various properties of dough and flour. It affects bread making property, gas retention, dough handling and bread texture. It can be determined by falling no. instrument. Other important factor that influences bread making property is hardness that is genetically controlled and is related to the degree of adhesion between starch and protein.

1.9.KEY WORDS

- Wheat: monocot, and its fruit, the grain/kernel, one seeded.
- Microscopy: a technique used for viewing magnified images.
- SEM: Scanning electron microscopy.
- Endosperm: inner part of wheat mainly composed of starch and protein.
- Germ: small portion of cereal grain rich in fat, protein and some vitamins.
- Bran: outer layer encasing interior endosperm and germ of cereal grain.
- Aleurone: layer of large cells under the bran coat and outside the endosperm of cereal grain.
- Gluten: a combination of two proteins, gliadin and glutenin, found in the endosperm of wheat grain.
- Glutenin: an alcohol insoluble protein fraction of wheat gluten.
- Gliadin: an alcohol soluble protein fraction of wheat gluten.
- Friabilin:a water soluble protein located on the surface of the starch granule.
- E.A.A.: dietary essential amino acids, like lysine, methionine.
- Scutellum: area surrounding embryo of cereal grain.
- Pericarp: consists of 2 to 4 layers next to the outer husk and outside the testa, of low digestibility, removed during milling, major constituent of bran.
- Pentosans: a complex carbohydrate yields five carbon sugars i.e. pentoses on hydrolysis.
- Amylase: a starch digesting enzyme.

1.10. SELF ASSESSMENT QUESTIONS

1.10.1. Give an account of the origin of wheat.

1.10.2. How can we classify wheat? Describe characteristics and uses of each class.

1.10.3. Elaborate the structure and composition of wheat grain.

1.10.4. What are various factors affecting grain size? Discuss.

1.10.5. Describe the factors responsible for wheat hardness/softness.

1.11. SUGGESTED READING

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POST GRADUATE DIPLOMA
IN
BAKERY SCIENCE AND TECHNOLOGY

PGDBST – 01

SHEAT GRAIN STRUCTURE, QUALITY AND MILLING

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PGDBST- 01 **B.S.Khatkar**

UNIT II: CRITERIA OF WHEAT QUALITY

STRUCTURE

2.0 OBJECTIVES

This unit provides information related to various classes of wheat. Botanical, physical and chemical characteristics of wheat quality are elaborated in this unit.

2.1 INTRODUCTION

The criteria of wheat quality are at least as varied as its uses. Wheat that is suitable for one product may not have properties suitable for another product. The wheat generally found suitable for bread making has been reported to be unsuitable for biscuit production. Incompatible use of wheat may cause production losses and inferior quality of end product. The functional parts of wheat kernel also have different uses; for example germ is used as a diet supplement or extraction of tocopherols (vitamin E), bran is used as feed for animals and endosperm for flour.

Several classes of wheat like durum, hard and soft are established by the different grain quality standard institutes around the world. The qualities of the different classes fit them for specific end uses (i.e. durum wheat is used for pasta products, hard wheat is used for bread production, whereas soft wheat is generally preferred for cookies, biscuits, cakes, etc). The differences between wheat of these classes are generally based on industrial application oriented, as apposed to the differences within classes due to variety, or with in varieties due to environmental conditions. A number of the classes also share common characteristics and uses.

2.2 BOTANICAL AND PHYSICAL CHARACTERISTICS

2.2.1 WHEAT SPECIES

Three species of wheat are grown in the world. (i) *Triticum aestivum* (ii) *Triticum compactum* and (iii) *Triticum durum.* The grains of these three species differ considerably in quality characteristics and the differences are reflected in the uses made of their milled products.

1. Triticum aestivum

A wide range of wheat quality characteristics is available in *T. aestivum*. Kernel hardness and protein content vary widely within this species. And outstanding characteristic of this species, from the standpoint of economic value, is that its flour is superior to that of all other species for the production of leavened bread products.

2. *Club Wheat (T. Compactum*)

This wheat is grown mainly in U.S.A. and Canada. Both winter and spring varieties are grown there. The kernels of club wheat have a soft texture and low protein content. Club wheat is not well suited for bread flour but is excellent for certain type of cake and pastry flours, where low protein content and weaker glutens are required.

3. Durum wheat (T. durum)

Kernels of this type of wheat are generally very hard in texture and rather high in protein content. Most of the durum wheat crop is used for the production of semolina or durum flour for pasta products because the qualities of durum gluten make it particularly desirable for this use but it is less suitable for bread making. Durum wheat class is preferred for pasta products mainly because of the following reasons:

a) Durum wheat has double concentration of xanthophyll (yellow pigment) as compared to bread wheat and thus it gives bright and yellow colour of semolina.

b) The semolina of durum wheat resists disintegration when cooked and gives firm texture and good mechanical strength of pasta products.

c) Durum wheat contains gliadin 45 subunit, which confers good cooking quality in pasta products.

d) Mineral composition of durum wheat is one and a half times greater than the bread wheat particularly for calcium, phosphorous and magnesium. These minerals play significant role in improving the cooking quality of pasta products.

2.2.2 WHEAT VARIETIES

Wheat varieties vary in their morphological parameters such as colour, shape, texture, width and the crease of the grain. These characteristics have some influence on the economic value and processing quality of wheat varieties. Thousands of wheat varieties are grown in the world and new varieties are usually bred with a specific purpose in mind. Varieties in *T. aestivum* wheat vary in quality characteristics having high protein content to low protein contents. High protein flour is used for bread and fermented products, whereas low protein flour is used for softer products such as biscuit, cake and cookies. The low-protein wheat of *triticum compactum* varieties are used primarily in cake and cookie production, and *triticum durum* varieties provide a substantial portion of the wheat to produce flour or semolina for pasta. Varietal differences in grain quality are great among the common wheats, less so among the durum wheats, relatively small among the club wheats.

2.2.3 **TEST WEIGHT (WEIGHT PER UNIT VOLUME)**

Test weight or weight per unit volume is most widely used and simplest criteria of wheat quality. Test weight usually determines the plumpness of the grain. It is basically a rough measure of density of grain in terms of weight per unit volume i.e. the weight (lb) per volume bushel. In the United States, test weight is expressed in terms of pounds per bushel, whereas other countries using metric systems, it is expressed in kilogram per hectoliter. The hectoliter weight (hL), indicating the weight in kg/hL (100 L).

Kernel shape and uniformity of kernel size are important factors affecting test weight, in as much as the influence the manner in which the kernels orient themselves in a container. The other important factors influencing test weight is the density of the weight. Density, in turn, is determined by the biological structure of the grain and its chemical composition including moisture contents. Weight per unit is an important datum in all wheat grading systems primarily because it gives a rough index of flour yield. Immature, badly shriveled, drought or disease affected wheat usually has a low test weight and gives correspondingly poor yield of flour.

2.2.4 **KERNEL WEIGHT**

Kernel weight usually expressed in grams per 1,000 kernels is a function of kernel size or kernel density. Kernel weight is considered superior in predicting the milling quality of grains as compared to test weight. In as much as large, dense wheat kernels normally have a higher ration of endosperm to non-endosperm components than do smaller and less dense kernels. It is considered that wheat varieties which are giving higher kernel weight give higher flour yield as compared to those having lower kernel weight. The electronic counter is used for thousand grain weight in grams. The general range of kernel weight is between 30-45 grams for bread wheat, where as in case of durum wheat it is between 35-55 grams. The advantage of kernel weight (1000 grain weight) is that the weight can be expressed on a desired moisture basis.

2.2.5 KERNEL SIZE AND SHAPE

Wheat varieties vary widely in size and shape of their kernel. This variation is seen even within the varieties. The variation in wheat generally depends upon many internal and external factors which are associated with the grain during its growth and maturing stages. Kernel size is closely related to kernel weight and would be expected to have an effect on flour yield. The size distribution of kernels in a wheat sample can be determined using a stack of sieves. The ‘theoretical flour yield’ can be determined by the total value of multiplying the percentage of above each sieve by a factor. The factor can be calculated using multiple regression analyses for a mill. Wheat kernels are usually classified into three categories based on visual observation and thousand kernel weight, as small (< 32.0g), medium (32.0-38.0g) and bold (>38.0g), whereas on the basis of shape they are classed as round, ovate, oblong (broader on both sides) and elliptical (elongated and bulged in the center). The shape of the wheat grain has great influence on the milling quality of the grain.

2.2.6 KERNEL HARDNESS

Wheat grain is generally classified into two-category (a) hard and (b) soft. Kernel hardness is a relative term, which is related to the disintegration of the endosperm during its separation from bran and germ. Hard grains when reduced to flour, there endosperm is cracked along the aleurone line and therefore yield more flour. On the other hand, most of the part of aleurone layer in soft wheat remains attached with endosperm that induces inconsistency in the flow of the flour while milling.

Hardness of wheat kernel relates to milling performance of wheat varieties. After milling, flour particles from the soft wheat will be fluffy and smaller size distribution, hard wheat breaks into larger particles. The flow characteristic of soft wheat flour is poor, whereas hard wheat flour will have good flow properties. A hard wheat requires more grinding force and thus produces flour with high starch damage suitable for breadmaking. On the other hand, soft wheat needs lesser grinding force and hence produces flour with lesser starch damage.

Wheat hardness is defined as a mechanical property of the individual wheat kernel or its resistance to crushing/grinding. Grain hardness may also be linked to genetic make of a wheat variety. It has been reported that a single gene located at short arm of chromosome 5D controls grain hardness. The presence or absence of an ‘anti-sticky’ protein is said to responsible for hardness or softness of wheat grains. This protein is defined as “friablin” which has 15K molecular weight. This protein is found present in soft wheat, whereas it is either found absent or if occurs the concentration of this protein remains very low in hard wheat. The friabilin occurs on the surface of starch granules and prevent bonding between starch and protein molecules. Thus, its presence makes a grain texture softer due to weak bonding of protein and starch molecules.

Several methods like pearling resistance, grinding resistance, particle size index, compression testing, penetrometer testing, near infrared refraction (NIR), single–kernel characterization system (SKCS) have been used to measure the hardness of the grain. None of these methods gives a direct measure of physical hardness of wheat grain but they give average property that may be correlated indirectly with hardness of grains. The SKCS gives a idea of kernel hardness by recording the force deformation characteristics during crushing of grain. The instrument test 300g wheat grains in 3-5 minutes. It weighs individual grain, measure its diameter, crushes each grain to determine its moisture content by conductivity and records the force deformation profile of grain during crushing.

2.2.7 RELATIONSHIP BETWEEN GRAIN CHARACTERISTICS AND MILLING PERFORMANCE

There is as yet no international consensus on how to combine physical quality traits to derive a milling index. The relative importance of these parameters in relation to milling yield potential of a wheat variety can be assessed by determining correlation coefficients of these individual parameters with flour yield. A significant positive correlation between kernel width and total flour yield is found in hard wheat variety but not in case of soft wheat variety. On the other hand, soft wheat variety demonstrates significant negative correlation with test weight, whereas hard wheat shows extremely weak negative correlation with test weight.

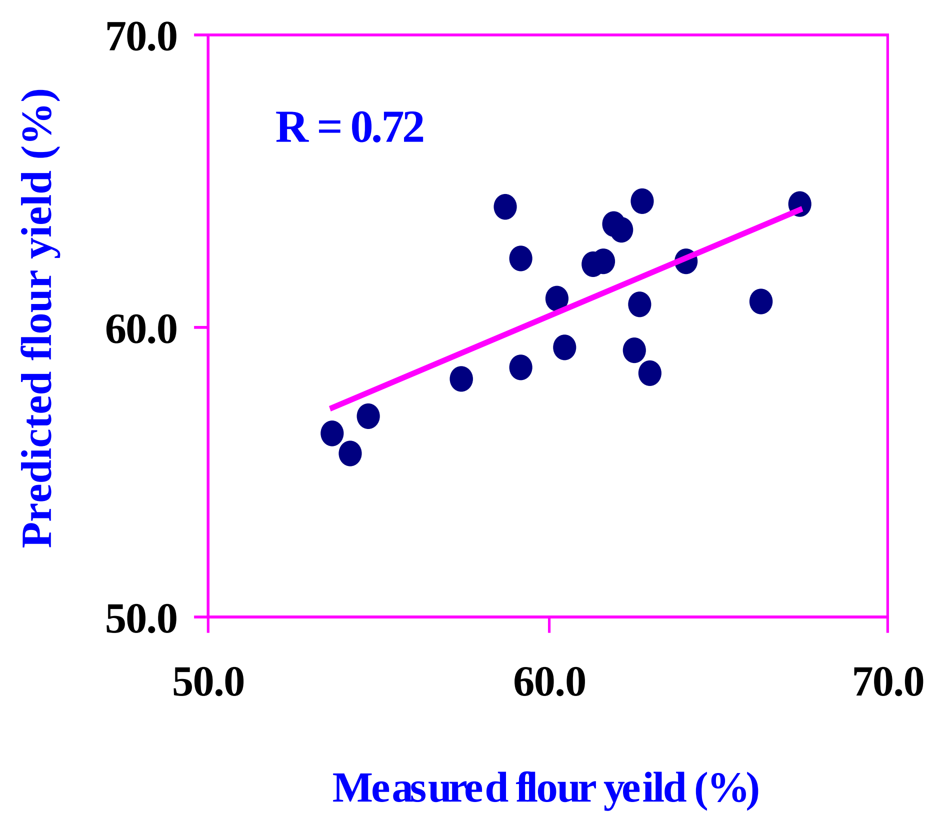
The following equation models can predict the flour yield of wheat varieties:

Flour yield (Hard wheat) = 36.2 – 0.30 TKW + 17.4 KW – 0.26 TW

Flour yield (Soft wheat) = 113.0 + 0.15 KL – 0.68 TW

Where, TKW = 1000-kernel weight; KW = kernel width; TW = test weight and KL = kernel length. These parameters can easily be measured in any laboratory. The above equations provide a correlation coefficient of r = 0.72 and 0.56 between measured and predicted flour yields for hard and soft wheat, respectively as shown in Figure 2.1.

Figure 2.1 Correlation between measured and predicted flour yield.



2.3 CHEMICAL CHARACTERISTICS

2.3.1 MOISTURE CONTENT

Moisture content is one of the most important parameter in judging the quality of wheat. Moisture content has direct economic importance because it is inversely related to the amount of dry matter in wheat. Moisture content has more significant effect on the keeping quality of the wheat. Dry, sound wheat can be kept for years if properly stored, but wet wheat may deteriorate dramatically within a few days. Moisture content is usually the principal factor governing the keeping quality of wheat. Near the critical moisture level, small differences in moisture content results in relatively large differences in keeping quality. At the time of harvest the moisture content of the grain ranges between 8-13 percent depending upon the climatic conditions. Different methods are used to determine the moisture content of the grain like Air oven method, Karl Fischer method, electric moisture method meter, etc. If the grains are not stored properly during rainy season the moisture content of the grain may rises as result of which certain bio-chemical changes occurs within the grain resulting in the deterioration of the quality of the grain.

2.3.2 PROTEIN CONTENT

The protein content of the wheat ranges from about 6% up to 18% depending upon variety, class and environmental conditions during growth. Flour containing at least 10% protein is usually preferred for the production of yeast leavened bread. To produce such flours, the wheat must contain at least 11% protein because about 1.0% of wheat protein is lost to the feed fractions when the wheat is milled in flour. Wheat grain with protein content of 8-10% is suitable for the biscuits flour productions. The quantity of protein present in flour is considered important in dough making. Cookies require a softer type of flour, which provides for structure building and leavening. The quantity of gluten in flour influences the flour strength. Stronger the flour, harder the cookies and less the spread with more puffing in the center. Standard cookies flour is generally a soft flour having protein content between 7.0 to 8.0 percent.

Table 2.1 shows the appropriate protein usually required of flour for different use. Different methods like Kjeldahl, NIR etc are used for determining the protein quantity in the wheat grains.

Table 2.1 Protein requirement of different wheat products

Wheat protein content (%)	Type of wheat	End product
13.0 and above	Durum	Macaroni products
11.5-13.0	Hard	Pan bread
10.0-11.0	Hard	Crackers
8.0-10.0	Soft	Biscuits, pies and cookies

2.3.3 PROTEIN QUALITY

The quality of protein plays significant role on the functionality of the wheat flour. The quality of the wheat protein have been recognized as factors having a decisive effect on the physico-chemical properties of wheat flour dough and consequently, on it’s handling properties and baking potential. Since these relative functions of wheat proteins have been attributed primarily to gluten forming proteins, protein quality determination in wheat or wheat flour is very often supplemented by a qualitative estimation of gluten. Different types of chemical tests are used to define the quality of the gluten proteins like SDS sedimentation volume, baking test of gluten, Pelshenke test etc.

Test baking method is generally adopted to assess the baking quality of wheat flour. However, it is time consuming and expensive. For this reason, several research groups have been searching for reliable alternative. Baking quality of wheat can be assessed directly on gluten samples. Moreover, conducting direct test on gluten also gives reliable differentiation among industrial quality of wheat varieties. The procedure is described as follows. To separate gluten from other constituents, the wheat flour is mixed with water. The native proteins of flour interact to form a chewing gum type of wet mass, which is called wet gluten. The wet gluten can be washed out using potable water. The wet gluten is dried to form a free flowing light coloured powder. Depending upon the variety, it has been noticed that wide variation in the quality of extracted gluten occurs. Baking tests is conducted directly on the wet gluten samples in order to assess the quality of gluten. Ten grams of wet gluten is taken and volumes of the gluten dough are measured. The gluten balls are baked for 20 min at 220 °C. Volume of the baked gluten can be determined immediately after baking. Photographs of two baked gluten samples are compared in Figure 2.2. The left sample picks up water rapidly and performs well in baking test, while the right one represents gluten that picks up water and agglomerates slowly and performs poorly in baking test.

Figure 2.2. Photographs of good (left) poor (right) quality baked glutens.

The glutens performing the best in the baking test (i.e. those glutens resulting above 125 cm^3 baked volume) all agglomerate well and develop into uniform ball easily when extracted from flour dough with water. Generally, gluten that agglomerate well and develop into a smooth uniform ball during the washing cycle yields higher wet gluten and performs well in baking test.

Using stepwise multi-linear regression analysis, the different experimental parameters are fitted into a model predicting the baking quality of gluten. The statistical analysis leads to the following model:

Gluten quality = 43.7 + 22.0 WG, where WG = wet gluten content (%). Here, gluten quality is expressed as baked volume of wet gluten. The equation parameter wet gluten (WG) can easily be estimated in any wheat-processing laboratory. The equation will give fairly good assessment of baking quality of gluten and wheat. The model does not have any requirement of sophisticated equipment or expensive ingredient. The test is rapid and will take only 10 minutes to predict and explain variability in the industrial potential of commercial wheat.

2.3.4 α-AMYLASE ACTIVITY

Highly important quality attribute of flour is its level of diastatic or amylolytic activity. Diastatic enzymes comprise alpha-amylase and beta-amylase. These enzyme acts upon damaged starch to produce sugars, which serve as food for yeast cells for proper gas generation during, bulk fermentation and proofing. Normally Indian wheat flours contain sufficient amount of beta-amylase but lack in alpha-amylase. However, sprouting of wheat increases alpha-amylase in the flour. The alpha-amylase exerts a major effect on both dough properties and final bread characteristics. Proper supplementation of flour with α-amylase results in a bread with improved crust color, finer grain and increased volume. Excessive malting of the flour, on the other hand, tends to decrease water absorption, impart stickiness to the dough, bring about a slackening of the dough, reduce loaf volume and produce inferior grain and texture in the baked product.

Many baking experts are of the opinion that the level of diastatic activity of a flour is perhaps as important to its baking performance as its protein, moisture and ash content. In recognition of this fact, several methods of measuring this activity are in use in milling and baking laboratories. Traditionally, these methods are of three types, namely (1) the determination of maltose production under specified conditions, (2) measurement of gassing power developed in a small sample of fermenting dough, and (3) measurement of viscosity changes by the amylograph in a flour slurry subjected to uniform heating. A relatively new technique, the "Falling Number" test, is more frequently used recently. It provides a quick means for determining possible sprout damage in wheat. The method is based on the ability of α-amylase to liquefy gelatinized starch. As a suspension of flour or starch is heated, the individual starch granules swell by taking up water and cause the suspension to thicken and become more viscous. In the swollen or gelatinized state, the starch cells become susceptible to attack by α-amylase, which splits up the long molecular chains of the starch. The reduction of the swollen gelatinized starch granules into dextrins and maltose causes a drop in the viscosity of the starch suspension. The rate and extent to which the viscosity of the heated suspension is reduced is a measure of the α-amylase activity. In the falling number method, the level of enzyme action is defined as "the time in seconds required stirring and allowing the stirrer to fall a measured distance through the hot aqueous flour gel undergoing liquefaction".

2.3.5 ASH CONTENT

Wheat usually contains 1.4 to 2.0 % ash on 14% moisture basis. Ash colour is closely related to the colour influencing components such as bran of flour. The bran, outer covering and aleurone layer have higher ash content than endosperm in wheat. Small or shriveled kernels have more bran on a percentage basis. Ash content reflects the quantity of mineral matter present in the flour. Higher bran contamination in flour indicates higher ash content. Milled products, which contain higher levels of ash content, are darker in colour. Thus, the primary objective of milling is to thoroughly separate endosperm from bran and germ. The efficiently of separation can be judged by several indirect methods based on measuring any constituent that is more concentrated in bran and germ. Since the mineral content of the bran is about 20 times that of the endosperm, the ash test fundamentally indicates the purity of flour or thoroughness of separation of bran and germ from rest of the wheat kernel. The ash test assumed greater importance in the milling trade than any other test for the control of milling operations. There are many factors which influence flour ash like environmental factors including rainfall and temperature, genetic make up of wheat variety and milling conditions such as tempering and grinding.

2.4 SUMMARY

Wheat classes and varieties are influenced by botanical, physical and chemical characteristics. Wheats are broadly classified into durum, hard and soft wheats. Different class of wheat is used for different end product. For example, durum wheat is used for pasta products; hard wheat is used for bread production, whereas soft wheat is generally preferred for cookies, biscuits, cakes, etc. The differences between wheat of these classes are generally based on industrial application oriented, as apposed to the differences within classes due to variety, or with in varieties due to environmental conditions. A number of the classes also share common characteristics and uses.

2.5 KEY WORDS

Test weight : It measures of density of grain. It is expressed in kilogram per hectoliter. The hectoliter weight (hL), indicating the weight in kg/hL (100 L).

Kernel weight : It is usually expressed in grams per 1,000 kernels, and it is a function of kernel size or kernel density

Diastatic enzymes : These enzymes act upon damaged starch to produce sugars, which serve as food for yeast cells for proper gas generation during, bulk fermentation and proofing.

Kernel hardness : It is a relative term. Hard wheat requires more grinding force and thus produces flour with high starch damage suitable for bread making. On the other hand, soft wheat needs lesser grinding force and hence produces flour with lesser starch damage.

Ash content : It reflects the quantity of mineral matter present in the flour.

2.6 SELF ASSESSMENT QUESTIONS

1. Define wheat quality. Classify wheat species and indicate their importance.
2. What are the major differences among wheat species?
3. Why durum wheat is preferred for pasta products.
4. Discuss physical grain characteristics that influence wheat quality.
5. Explain basis of wheat variety hardness/softness. How grain hardness can be determined?
6. What is the importance of moisture content of wheat grain with respect to storage and processing?

7. Explain the significance of protein quantity and quality in bakery products.

8. What is the importance of alpha-amylase in bakery products? How we measure the activity/conc. of alpha-amylase in wheat grain and flour?

9. Ash content is considered an index of flour quality. Justify the statement.

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UNIT III: THE MILLING PROCESS AND MILLED PRODUCTS

STRUCTURE

3.0 OBJECTIVES

Thorough study of this unit will enable the reader to understand:

- Aims of flour milling
- The milling process
- Milling by-products

3.1 PREPARATION OF WHEAT FOR MILLING

It is important to preserve the quality and economic value of wheat grain as it moves from the field into storage bins at the mill site. Proper storage conditions are important to avoid damage to grains from insects and moisture or other adverse storage conditions. Moisture and temperature are two main factors that influence the quality of grains during storage.

In areas where wheat is harvested at high moisture content, it should be carefully dried to moisture content below 12.5%, a level regarded as safe for storage. Wheat exposed to high temperature and high relative humidity is not desirable. In some dry areas wheat arrives at the mill with 8-9% moisture content and water can be added to the wheat after cleaning to raise its moisture to a desirable level of 12.5%. By adding moisture to the wheat before storage, the miller can subsequently reduce the tempering time of dry wheat in the mill. The insect growth and spoilage are related to the moisture content and temperature of the stored wheat. Timely measures should be taken to control the moisture and temperature of the wheat by aerating storage bins. Plant inspection, good housekeeping, fumigation, and other measures such as heat treatment of the facility can control infestation in the flourmill. Measures should also be taken to prevent harbor of material in “dead corners” where insects could propagate.

Prior to storage of grains in bins, it is important to take some measures to kill all kinds of insects in the bins. Heating of facilities may be used for a long enough period to kill all insects. A temperature range of 50-55° C in all parts of the mill for duration of 10-12 hours is sufficient to destroy all insect life.

Pre cleaning of wheat at the mill should be done before storage in the mill bins or silos. Magnets, large-capacity sieve cleaners, and strong aspiration remove large chaff, dust and metals from wheat grains. Pre cleaning removes contaminants from wheat to allow its longer storage, more efficient usage of storage space, and subsequently better and uninterrupted flow from the bins. The exhaust system including ducts, suction fans, and air filters or dust collectors should be kept clean and in good conditions to avoid loss of material and dust explosions.

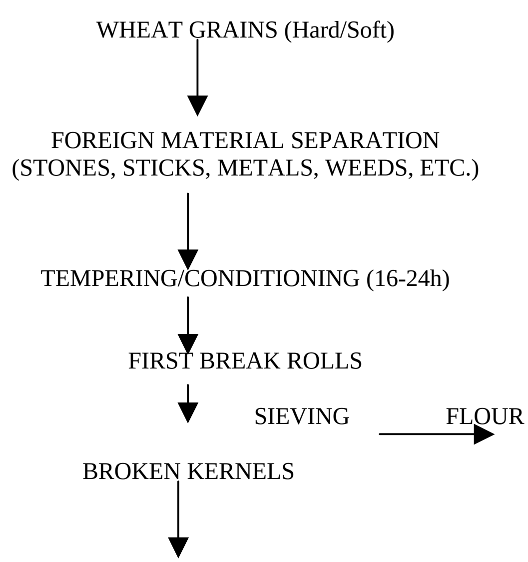
3.3 AIMS OF FLOUR MILLING

The primary aim to wheat flour milling is twofold: (1) to separate bran and germ of the wheat kernel from the endosperm and (2) to grind the separated endosperm into suitable particle size of flour. The efficiency of mill relates to clean separation of bran and germ from endosperm. The objective of miller always remains to deliver flour of consistent quality. The quality of flour should not vary from batch to batch. The term ‘extraction rate’ is used indicate the flour yield from a given quantity of wheat. An extraction rate of 100% indicates that 100% of the wheat grain is delivered as flour. This is also referred to as whole-wheat meal. However, commercial grade flour generally has 70% extraction rate, which is refereed to as straight-grade flour.

3.3 THE MILLING PROCESS

3.3.1 GENERAL PRINCIPLE

The flour-milling process consists of numerous stages including receiving of wheat, cleaning, blending, storage, tempering/conditioning, breaking, sieving, purification and reduction. General process outline of roller flour milling of wheat is presented in Figure 3.1. The efficiency of milling process depends upon type of wheat, milling equipments used and skill and experience of the miller. The milling system consists of two types of rolls, break rolls and reduction rolls. The break rolls are fluted and reduction roll surfaces are smooth. These rolls have different functions in milling. The break rolls open the wheat grains from the its crease and scrape endosperm. The reduction rolls reduce or grind the large endosperm particles into flour. The rolls have diameters ranging from 180 to 350mm and up to 1500 mm in length. The rolls rotate at different speeds. The ratio of the speeds is called the differential. The break rolls rotate at about 650 rpm, while reduction rolls rotate at about 500 rpm. Differentials speed range from 2.5:1 to 1.5:1 in the break and reduction rolls, respectively. With higher differential, there is a larger shear effect between the rolls, while with lower differential, compression is more significant.



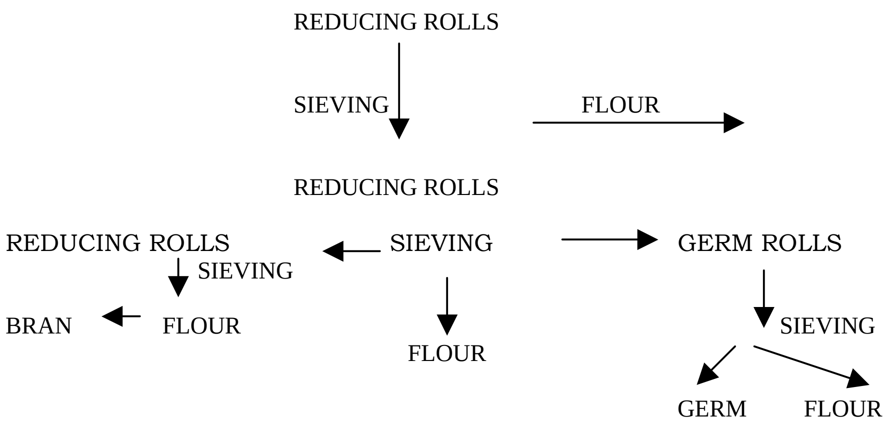


Figure 3.1 ROLLER FLOUR MILLING PROCESS

3.3.2 CLEANING

Proper cleaning of the wheat prior to milling ensures that bacteria, mold, undesired seeds, infested kernels, shrunken and broken kernels, and other foreign materials do not contaminate the mill products or damage the equipment. Cleaning carried out based on the following differences between sound grains and unwanted materials: size and dimension, shape, specific, gravity, different surface friction, magnetic properties, friability under impact. Shrunken kernels have higher ratio of bran to endosperm than sound kernels and hence cause reduction in flour extraction. Exposed endosperm of broken kernels would affect significantly the tempering water distribution in the wheat and cause a deterioration of milling quality.

Magnets or metal-removing equipment separate foreign materials that could damage equipment or generate a spark in fast moving and precisely designed equipment. Sparks in a confined space with dusty concentration could cause a dust explosion. Initially, the foreign material is removed by a series of screens of selected apertures that remove matter either smaller or larger in size than the wheat kernels.

Gravity separators remove impurities similar to wheat in size but different in specific gravity. Adjusted air currents are drawn through a layer of wheat moving on a tilted screen. Stones or other materials heavier than wheat are segregated and remain closer to the screen. The lighter wheat floats down the screen, while the heavier stones climb the vibrating screen to the outlet. Following the gravity separators, machines such as the disc separator remove impurities that are similar in size but different in shape from the whole-wheat kernels. The disc separator utilizes a series of rotating discs with indentations or pockets on both sides to effect separation. The discs rotate within the machine and raise those kernels that fit into the pockets. The picked-up particles are dropped into channels between the discs. Pocket configurations depend on the size and shape of the seeds and grain to be separated. The bulk of the wheat is controlled with a gate at the outlet end of the machine. The efficiency of separation is also controlled with a gate at the outlet end of the machine. The efficiency of separation is also controlled by the option to divert picked-up particles into a screw conveyor that can return them to the head end of the machine.

Another machine using the principle of shape differences is the Indentation cylinder. This device has a lower capacity and is less efficient than the disc separator. Particles are picked up by indentations in a rotating metal cylinder and dropped into a collection trough. The disc separator or the indentions cylinder pockets sizes can be selected from manufacturer catalogs to separate shorter particles from the bulk of wheat or the wheat kernels from longer kernels, such as those of barley and oats.

Dry scouring of the wheat removes any dirt adhering to the kernel. In the scorer a rotor bounces the wheat against the wall of the machine, which may be of a perforated sheet metal, a steel wire woven screen, or an emery surface.

3.3.3 TEMPERING/CONDITIONING

Tempering refers to the process of adjustment of the moisture level of wheat grains before milling. The primary aim of tempering is to mellow endosperm and toughen bran. Bran that absorbs proper amounts of moisture becomes elastic and will not disintegrate during grinding to contaminate the flour with fine particles. Mellow endosperm breaks off the bran during grinding, and less power is required to reduce large pure particles to flour. On the other hand, an excessive moisture level softens the wheat endosperm to a degree where it does not have the resistance to break down to sharp particles that is important for efficient sieving and separation from the bran. Another objective of wheat tempering is to equalize the hardness of the different kernels in the wheat mix before processing.

The difference between the term tempering and conditioning relates to the temperature at which wheat is treated with water. If the process is carried out at room temperature, then it requires 18-72 hours for moisture equilibrium and it is called tempering. If the process is carried out at elevated temperature, then it takes 8-18 hours for water equilibrium in the grain and the same process is known as conditioning. The efficiency of tempering/conditioning depends upon (1) initial moisture content of grains (2) temperature and time of the process (3) moisture distribution in the grain and (4) grain hardness. Moisture pick-up by wheat through capillary action increases slightly and linearly with increasing water temperature. Water penetration and optimal distribution in the wheat kernel is also a function of wheat size and shape. Water penetrates at different rates into small, medium, and large kernels of hard wheat. Three factors affect the rate and level of water penetration into the kernel: temperature, amount of water and time.

The ideal temperature for general tempering conditions is about 25°C. Higher temperatures will increase the rate of water penetration into the kernel. Temperatures above 50°C will change the endosperm starch and protein characteristics. The wheat delivered to the grinding stages should have the right moisture content and preferably a temperature of about 25°C. The bran of cold wheat below 15°C will fracture excessively in the breaks and result in higher ash in the flour. At optimum moisture and temperature, a drastic increase in flour yield and quality can be achieved. During the milling process, about 2% of the total moisture in the mill materials evaporate. Accordingly, the amount of water added to the wheat should be adjusted based on the raw wheat moisture and environmental conditions in the mill. In general hard wheats are tempered to 16.0-17.0% moisture contents, whereas soft wheats are tempered at 14.5-15.5%. The average tempering times are 36, 10 and 6 hours for hard, soft, and durum wheats, respectively.

3.3.4 BREAKING OR BREAK SYSTEM

The initial grinding stages in the milling process are named “breaks.” The breaks are used in the grinding steps of the milling process to separate the bran, germ, and endosperm from each other. The success or failure is measured in the level of achieving, as efficiently as possible, complete separation between the kernel parts. Between corrugated rolls there always exists a small gap, which is absent in smooth reduction rolls. In the conventional milling of hard and durum wheats, the objective is to produce minimal amounts of flour in the breaks but a maximum of clean endosperm chunks. However, with soft wheat, because of the softer, less dense endosperm, the percentage of flour extracted from the breaks in conventional milling is higher than that from hard and durum wheats.

The corrugations on the roll surface are grooves with front and back angles. The corrugations are cut in a spiral with relation to the roll axis ranging in the order of 4-16%. The inclination would be expressed in inches per foot or in percent per roll length. The number of corrugations on the first break rolls would be about 4/cm. In later stages there is a gradual increase in the number of corrugations per inch (smaller corrugations) on the roll surface.

The objective of break rolls is to open the kernel. The shape and depth of the first break roll corrugations should be such that the kernels fits into it. Optimum results in the first break are achieved when the kernels are opened exactly at the crease by the fast-moving roll. The second break rolls and the subsequent break rolls scrape the endosperm from the bran. As the bran flakes get smaller toward the final breaking stages and the endosperm layer attached to it becomes thinner, gradually smaller corrugations or a larger number of corrugations per inch of roll surface are used.

3.3.5 SIEVING

The mixed or heterogeneous material is sieved by sieving machine called a ‘plansifter’, which encloses up to 8 compartments each having up to 26 sieve frames. In the plansifter, particles of the grounded material are separated according to size. The sieves in a plansifter section are divided into groups. At the top of the section, there are usually coarser sieves separating the larger material that flows out of the plansifter through a side channel. The material passing through the sieve is either transferred out of the machine or directed down to finer-aperture sieve, a hard rubber balls or cotton pads bounce on sieve to keep the sieve clean.

3.3.6 PURIFICATION

Purifier machine is one in which air currents are drawn from one to three layers of sieves while sieves are in reciprocating motion. The material that is separated using purifier is composed of particles of the same size range but having different densities. The purifier's main purpose is to separate particles into fractions of pure endosperm, a mixture of particles to which bran is attached, and bran particles. This is achieved by using sieves and air currents. The purifiers classify the material into several fractions according to size, shape, and specific gravity. The heavier endosperm particles move closer to the sieve surface while the material with more bran floats on top. At the head end of the purifier the purest and most dense endosperm particles pass through the sieves. Materials with more bran attached pass to sizing rolls through the coarser sieves.

3.3.7 SIZING

The objective of the sizing is to reduce the particle size and separate the attached bran fraction from the endosperm. Material from the sizing stages can be diverted to purifiers, to middlings for final reduction, or to flour as a final product. However, the miller tries to refrain from severe grinding in the sizing stage to avoid production of flour that may be contaminated by the presence of bran. Some millers use corrugated rolls on sizing stages, while others use smooth rolls. Smooth rolls have advantage of delicate effect and produce lower-ash flour than corrugated ones. When corrugated rolls are used in sizings stages, the corrugation features are adjusted to the particle size and the bran adhering to them.

3.3.8 REDUCTION

Coarse and fine pure endosperm particles from breaks, purifiers and sizing in the mill are reduced to flour particles using reduction or smooth rolls. The speed differential between reduction rolls is kept in the range of 1.15:1-1.8:1, i.e., much lower than in breaks or other corrugated rolls (2.5:1). The low differential causes higher pressure and lower shear forces between the rolls. High pressure is exerted on the material in the reduction stages. However, the pressure should be optimized for each reduction stage. The reduction system may affect the quality of the end product as high compression and shear forces are applied. The adhesion between the starch granules and the protein matrix of the endosperm cells is stronger in hard wheat than in soft wheat. Therefore, flours from soft wheat disintegrate easier in milling and produce finer flours than those of hard wheats. Millers adjust roll settings to produce flours of coarser granulation from weaker wheats and finer granulation from stronger wheats to achieve optimum results in baking.

The starch is damaged in the process of producing flour of finer granulation from hard wheats. The starch damage is lesser in the case of soft wheat due less severity of grinding. Starch damaged by milling absorbs five times more water during the dough process and is more susceptible to enzyme attack. Damaged starch of flour for bread making should be in the range of 7-8%.

3.4 FLOUR STREAMS AND EXTRACTION RATES

Flours obtained from different streams differ in physical appearance, chemical analysis, or baking properties. Flour streams includes streams from break and reduction rolls. The flour streams are composed of varying amounts of different parts of the wheat grain. Combination of all streams gives a “straight-grade flour”. It is possible to combine flour streams in different ratios to produce simultaneously two or more final flours that differ in colour, ash content, protein content, dough-handling properties, and bread baking characteristics.

Flour streams from the head end middlings, primary sizings, and in some cases that of second and third breaks originate from the centre of the wheat kernel. The blend of these flour streams is called “patent flour.” Patent flour is about 75% of the total flour, is the whitest, and contains the lowest relative amount of ash (0.38-0.42%). Other flour streams are distinguished from the former by higher ash and protein contents, darker colour, and inferior baking qualities. These flour streams can be combined to make up “first-clear flour.” First-clear flour is about 20% of the total flour and contains about 0.75% ash. “Second-clear flour,” made up the rest of the streams, is 3% of total flour and contains up to 1.2% ash. Blending part or all of the first clear into the patent flour makes the “baker’s patent.”

Flour extraction rate refers to the proportion of the wheat recovered as flour by the process of milling. It may be expressed as a percentage of either the raw material used or the products obtained. Thus, flour extraction rate may be calculated in at least the following different ways.

1. Based on uncleaned wheat as received

$$\% = \frac{\text{Weight of flour} \times 100}{\text{Weight of uncleaned wheat}}$$

2. Based on clean dry wheat

$$\% = \frac{\text{Weight of flour} \times 100}{\text{Weight of clean dry wheat}}$$

Table 3.1 Chemical composition of flour with respect to extraction rate

Constituents (%)	Extraction rate (%)		
	70	**80**	**100**
Protein	8-10	8.5-11	9-13
Starch	70-75	70-73	65-70
Ash	0.40-0.45	0.60-0.70	2.0-2.5
Lipids	1.0-1.5	1.5-2.0	2.0-2.5

3.5 MILLING MACHINERY

The major mill machines essential to separating wheat grain into flour, bran and germ include the roller mill, the sifter, and the purifier, which are described below.

3.5.1 ROLLER MILL

A modern roller mill consists of two pairs of cast-iron rolls mounted in a heavy cast-iron frame. These rolls have diameter of 225mm (9 in.) or 250mm (10 in.), and lengths of 61 to 125 cm. Each pair is driven separately and having separate feeding and adjustment mechanisms. Thus, a roller flourmill essentially is two pairs of rolls in one frame. The upper roll of a pair is carried in fixed bearings, but pivot arms, which may be adjusted to vary the distance between the rolls, support the lower roll. Adjustment of the gap between rolls gives different degrees of grinding. Cleaning brushes are mounted in the frame to remove any material that adheres to the surface of the break rolls. Steel scrapers or hard strips are used instead of brushes in the case of reduction rolls. The rolls rotate in opposite directions at differential speed. The lower roll moves at lower speed than the upper roller, thus shearing action is produced on the grains. The break rolls have flutes or corrugations along the length of the roll, whereas reduction rolls have smooth surface.

3.5.2 SIFTER

It consists of several sieves, rotating in a horizontal plane. The sieves are arranged in sections and each section accommodating as many as 30 layers of sieves. The sifter may have up to sections. The sieves of a sifter fitted with cloth for coarse separations and nylon or silk mesh for finer separations of flour and middling. The operation of a sifter is simple. Material enters the top of the machine. The rotary motion of the sieves directs the finer, heavier particles to work their way down through the layer of ground material, leaving the coarser, lighter particles on the surface of the layer. The process of grading the material by size is repeated as it flows through the machine with each classification having its own outlet. Regular inspection and cleaning of sieves must be done for better operations. This is needed because the sieve apertures can be clogged with floury or fibrous particles after prolonged operation, reducing the efficiency of the machine.

3.5.3 PURIFIER

It consists of a frame of 2m length with a slight downward slope. The frame carries a number of sieves, usually four per frame, that is clothed with progressively coarser material from head to tail end. The compartment above the sieves is connected to an air trunk. The sieve bottom is kept open to the atmosphere. Air currents are drawn through the total area. Valves, set in sections of the compartment and the main air trunk, allow adjustments to be made to the air volume passing through the machine. A drive oscillates the frame longitudinally. This motion agitates and stratifies the stock on the sieve into layers, the heavier endosperm particles moving closest to the sieve surface. The combination of oscillation and slope of the sieve causes the stock to travel slowly along its length.

3.6 MILLING BY-PRODUCTS

The by-products of flour milling include bran, wheat germ, and the "clean-out" of the cleaning house. These products represent about 25% of the original grain and thus they are of considerable economic significance to the miller. Impurities of the cleaning house are called "screenings. This is processing into animal feeds. The fine and coarse bran is separated and used for animal feed and are also used to fortify bakery and other food products to enhance the fibre contents.

Wheat germ, which constitutes 2-3% of the whole wheat kernel, is used as food and pharmaceuticals. Wheat germ is therefore a valuable, although minor, milling by-product. Its recovery is poor in mills having no special equipment for germ recovery. Mills with sophisticated germ recovery systems can yield as high as 1.5-2.0% germ recovery. Wheat germ can be separated in mills on the basis of size and specific gravity differences with flour particles.

3.7 SOFT WHEAT MILLING

The difference in hardness of endosperm texture between soft and hard wheat is the main reason for differences in their milling procedures. Soft wheat is milled to fluffy flour mainly for the manufacture of biscuit, cookies and cakes. Soft wheat kernels are wider and have a lower specific weight than hard wheat kernels. Accordingly, cleaning machinery must be adjusted to the physical characteristics for efficient separation of unwanted materials. The endosperm structure of soft wheat is softer and open, allowing water to penetrate at a faster rate through the capillary spaces in the endosperm. Therefore, tempering moisture and time required in soft wheat is lesser than hard wheat.

Endosperm of soft and hard wheats fractures differently during the milling process. Soft wheat endosperm is amorphous and crumbles into smaller particles, whereas hard wheat is more crystalline and breaks into large chunks of endosperm while. The soft wheat endosperm requires less grinding force during the milling and thus produces finer flour particles with lower levels of starch damage compared to hard wheat. In soft wheat mill there is requirement of larger sifter area than the hard wheat mill. This is required mainly to overcome difficulties in sieving of fine flours.

3.8 DURUM WHEAT MILLING

Durum wheat is milled into a granular product known as semolina for pasta production. For durum wheat milling tempering is done in two or more stages keeping the tempering time short (4-5 hours) as in case of durum wheat it is not required to mellow or soften the endosperm but to toughen the bran only. Nearly 2% water is added 20min prior to milling for improving toughening effect of bran that help in producing clean semolina with minimum of bran contamination. Durum wheat milling is different from hard or soft wheat flour milling as to achieve maximum extraction of granular endosperm, more break and corrugated sizing stages are used. The number of purifiers used in semolina milling is significantly higher than in conventional flour milling. In durum milling the miller sends materials to purifiers with much narrower particle size ranges than in flour milling to differentiate more sharply between the different characteristics of materials based on size, shape, and specific gravity.

3.9 SUMMARY

Wheat milling is considered complex due to presence of central crease in the grain. Roller flour mills are recommended to separate the wheat fractions such as endosperm, bran and germ. The efficiency of milling process depends upon type of wheat, milling equipments used and skill and experience of the miller. The roller flour milling system consists of two types of rolls, break rolls and reduction rolls. The break rolls are fluted and reduction roll surfaces are smooth. These rolls have different functions in milling. The break rolls open the wheat grains from its crease and scrape endosperm. The reduction rolls reduce or grind the large endosperm particles into flour. The flour milling process consists of numerous stages including receiving of wheat, cleaning, blending, storage, tempering/conditioning, breaking, sieving, purification and reduction.

3.10 KEY WORDS

Tempering : It refers to the process of adjustment of the moisture level of wheat grains before milling. This is carried out at room temperature. It requires 18-72 hours for grains to attain moisture equilibrium.

Conditioning : If tempering is carried out at elevated temperature, then it takes 8-18 hours for water equilibrium in the grain and the same process is known as conditioning.

Purifier : It is a machine in which air currents are drawn from one to three layers of sieves while sieves are in reciprocating motion. The material that is separated using purifier is composed of particles of the same size range but having different densities.

Sizing : The objective of the sizing is to reduce the particle size and separate the attached bran fraction from the endosperm.

Flour streams : The flour streams are composed of varying amounts of different parts of the wheat grain. Combination of all streams gives“straight-grade flour”.

Flour extraction rate: It refers to the proportion of the wheat recovered as flour by the process of milling. It may be expressed as a percentage of either the raw material used or the products obtained.

3.11 SELF ASSESSMENT QUESTIONS

1. Why wheat is milled into flour and other milled products?
2. Why different wheats require different milling procedures?
3. Describe general procedure of wheat milling.
4. Explain major functions of tempering. Differentiate between tempering and conditioning of wheat.
5. What do you understand by the term extraction rate? How it influences the composition of wheat flour?

6. Which are the millings-by products? Give a brief account of milling-by products.

7. Discuss in brief the milling of soft and durum wheat milling.

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PGDBST- 01 **B.S.Khatkar**

UNIT IV: EXPERIMENT MILLING AND MILLING RESEARCH

STRUCTURE

4.0 OBJECTIVES

Thorough study of this unit will enable the reader to understand:

- Air classification of flour stream
- Milling machine automation
- Experimental milling
- Model predicting milling yield of wheat varieties

4.1 AIR CLASSIFICATION

Air classification process was developed in USA in 1960 to classify flour mixture by means of air currents. In air classifier, the finer particles of flour are carried along the air current, whereas larger particles of higher weight are collected along the periphery of the classifier. It is a physical separation of flour into fractions of higher protein and starch contents. The separation is achieved based on particle size and density. Air classification of flours is used where there is a demand for extremely precise specification of granulation and protein content of flour. Flour with uniform particle size has the advantage of uniform baking. In general, soft wheat millers use about 35% more air classifiers. Air classification technique makes flour suitable for different purposes. Same flour can be made suitable by this technique for biscuit, cake and bread.

Commercial flour particle granulation is between 0-150μ. Flour with smaller particle in the range of 1-17μ contains a high percentage of protein. On the other hand, flour with particle size range of 17-40 μ will usually be higher in starch content and lower in protein content. It is not practical to separate particles of less than 73 μ with conventional sieves.

Accordingly, particles are segregated by air using differences in particle shape, specific gravity, and size. Classifying flours to a granulation of between 17 and 40µ will produce very low protein flour that can be used for special cake mixes. The fine fractions in the range below 17 µ are blended with flours to increase protein levels. To increase the efficiency of the air-classifying system, millers use pin mills to disintegrate chunks of endosperm larger than 40 micrometer in order to release the starch granules that are embedded in the protein matrix.

4.2 TEMPERING

Conventional tempering generally fails to provide adequately uniform mixing of grain and water. Thus, it becomes difficult to add more than 3% water in one step, as excess surface moisture then interfered with the flow of grain through the hopper outlet. Moreover, as moisture distribution itself is not uniform, a longer-than-necessary tempering time is required to ensure both adequate moisture penetration within kernels and adequate moisture uniformity among kernels.

To improve moisture penetration and to reduce tempering time some developments have taken place recently, which are explained below. An instrument called ‘Intensive Dampener’ is used recently in mills to ensure both adequate moisture penetration and adequate moisture uniformity. This causes vigorous mixing action with provision for steam addition. This system has been widely accepted, and temper times have been reduced substantially. The effectiveness of the new tempering equipment has been greatly increased by the introduction of on-line automatic moisture control equipment such as moisture sensor. With microcomputer, it gives a continuous indication of the instantaneous moisture content of the wheat as it flows past a sensor located in a special chute. Microwave energy is specifically absorbed by water in the grain, and the surviving microwave signal is sent to the microprocessor as a measure of the quantity of water present. Bulk density of the grain is similarly measured with transmitted γ-rays. The microcomputer continuously calculates the percentage of moisture in the grain, with automatic compensation for grain density and temperature. This permits accurate moisture measurement and positive feedback control during the tempering process. The microcomputer processes the receives signals from the chute sensor, then displays and compares the grain moisture level with the preset target. Correcting signals are sent to the operator panel, where transducers convert electrical signals to pneumatic control signals. The moisture of the wheat entering the tempering mixer is measured and ensures consistency in the moisture content of the wheat being sent to the tempering bins.

4.3 AUTOMATION

In recent years milling operations have been automated and computerized. These developments have been induced for precise and simple monitoring of plant operation, flour yields, and for rapid generation of production reports. These measurements are achieved largely through the use of microprocessor-based controllers/sensors. These systems perform the following important functions.

1) flour extraction monitoring, correcting if there is any deviation from target

2) displaying the status of production

3) generating daily, weekly, monthly and yearly reports on production

4) setting audiovisual alarms to warn of emergencies

5) monitoring digital and analog sensors placed at critical points in the process

6) activating start-up sequences for equipment in the mill and

7) controlling the flow of additives to flour

The full potential of such systems has not yet been fully utilized. Many millers have already installed, or are planning to install, such yield-management systems in economically developed countries. In developing countries like India such automated systems are still a distant dream. It may take some more time to adopt and take advantage of these systems.

4.4 EXPERIMENTAL MILLING

Experimental or laboratory wheat milling is a general term referring to milling procedures conducted on small scale under strict control. Experimental milling data is found useful in the evaluation of lines from wheat breeding programs, prediction of the end-use quality of commercial samples, and research investigations. Many commercial flourmills use experimental milling to monitor mill performance and to obtain advance information on the properties of incoming wheat shipments.

For an effective experimental milling program accuracy and reproducibility of results is important. The first step in ensuring accuracy and reproducibility is minimizing sources of error, thereby reducing experimental error sufficiently to detect significant differences. In experimental milling, the major sources of error originate from incorrect sampling, inappropriate tempering, uncontrolled variation in ambient conditions, condition of equipment, and inadequate standardization of procedures. A homogeneous sample, representative of the whole, is essential if the experimental milling results are to be significant.

Tempering has a substantial effect on the experimental milling results. There is strong correlation of tempering moisture with flour properties such as flour yield, colour and ash content. As the tempering moisture increases, the flour yield decreases, ash content decreases and flour color improves. Hard wheat offers more tolerance to added water than soft wheat.

Several factors affect tempering time. Kernel hardness is considered the most significant factor, as tempering time may range from 6 hr to more than 24 hr depending up on hardness of grain. Thus, it is advisable that the miller should determine the hardness of the wheat grain by an appropriate test, such as the particle size index or pearling index. Grain protein content and initial moisture content also affect tempering time. Temperature is another significant variable. As temperature increases, the rate of moisture penetration increases and tempering time reduces. These factors must be controlled to for reproducible tempering of grains.

The need for reproducible tempering is understood and it is taken care by most wheat scientists, but the effect of ambient temperature and relative humidity on experimental milling performance is often overlooked. It is shown that flour yield, granulation, moisture, ash, maltose value, and baking quality are all affected by mill room environment. Relative humidity has a greater effect on milling results than temperature changes. When relative humidity declines, durum wheat semolina quality i.e. ash and color deteriorates, leading to spaghetti that is duller and darker. Thus, control of relative humidity is essential to obtaining precisely reproducible results in experimental milling. If the mill room environment cannot be controlled, relative results can be obtained only if a standard reference sample is milled on the same day under the same environment conditions as the test sample.

Coming to the equipment, the major factors affecting consistency of results include roll-grinding conditions; wheat feed rate, and equipment maintenance. Incorrect or poorly controlled roll grinding can influence flour properties enormously. For instance, reduction roll grinding conditions affect hard wheat flour ash, flour color, and starch damage. Similarly, heavy grinding in the break system adversely affects ash content and colour of all flour streams. Grinding condition influences the extent of starch damage. Heavy grinding causes excessive damage to starch, whereas insufficient grinding results in lower than required starch damage. Variations in starch damage affect physical dough properties, baking properties, and susceptibility of flour to the effects of α-amylase.

A gradual increase in the grinding roll temperature occurs in the Buhler laboratory mill during the first several hours of operation. During extended milling operation, the mill warms that leads to increase in the extraction rate and a corresponding increase may be observed in flour ash and flour color. The rolls expand as they warm during milling, thereby increasing the grinding action, which, in turn, increases the production of damaged starch and alters the physical dough properties and baking performance of the flour. On the other hand, the opposite effect of warming on Brabender Quadrumat laboratory mills is reported. Performance of mill equipment such as sifters as well as grinding rolls is also affected by the feed rate of wheat to the mill. Efficiency of grinding and sifting decreases as feed rate increases. In an automatic mill, as feed rate increases, sifting efficiency decreases, resulting in movement of flour farther down the mill. Flour extraction declines and starch damage increases due to regrinding of unsifted flour. Soft wheats should be fed into the mill more slowly than hard wheats because soft wheats sift less readily than hard wheats. This suggests that feed rate should be adjusted each time a different class of wheat is milled.

Finally, reliable results of experimental milling can be achieved only if all equipment is maintained well. A strict maintenance program is required to avoid malfunctioning and unnecessary breakdown of milling equipments. Care must be taken to ensure proper rolls alignment. Bearings, belts, and drives should also be kept in good working order, and those roll surfaces are kept in good condition. Sieves must be inspected and cleaned regularly. In addition, standard control samples should be milled each day to provide a regular test of mill performance and laboratory analyses.

4.4.1 PROCEDURES AND EQUIPMENTS

In the preceding paragraphs precision and accuracy of milling operations and equipments have been addressed. In this section experimental milling will be discussed from laboratory mills to large-scale pilot mills.

Experimental milling is practiced to assess milling quality of wheat. In any milling operation, the first and foremost unit operation is cleaning of wheat grains. Cleaning devices, such as the dockage tester, which removes foreign material and damaged wheat kernels, is widely used. In the absence of such equipment, wheat samples can be cleaned using a series of sieves of sizes appropriate to retain sound wheat kernels but to reject foreign material and damaged wheat kernels. It is also advised to use an experimental scourer for removing surface dirt and insect-damaged kernels from cleaned wheat. A number of equipment has been suggested to facilitate rapid, uniform tempering of wheat samples for experimental milling. Equipment includes rotating tubs or drums, a rotary shaker and a wheat washer. Several methods have been suggested to reduce tempering time for experimental milling. Tempering time can be reduced from overnight to two to three hours if a wetting agent is added to the tempering water, with no apparent effect on flour extraction or flour quality. More recently, it has been reported that total tempering time for hard and soft wheats can be reduced to 30 min by using a

15-min preliminary temper, a prebreak grinding pass, and a 15-min final temper.

Experimental milling equipment is available commercially in numerous shapes and sizes. Some of them are described next. A number of laboratories milling procedures have been described for use primarily for plant breeding programs. The most commonly used commercially available laboratory mills is the Brabender Quadrumat Junior and Senior mills. The Brabender Quadrumat Junior mill is an automatic compact unit that makes three grinding passes using four 3-inches diameter rolls. The mill produces low-and high-ash flours and bran from as little as 100g of wheat. The Brabender Quadrumat Senior mill has two four-roll units, one for break passes and one for reduction passes. The Brabender Quadrumat Junior mill provides a reliable method of producing flour of sufficiently good quality for large-scale wheat quality testing programs.

Commercially available equipment is often modified to achieve the desired combination of small sample size, reliability, and sample throughput for early-generation wheat screening. Buhler laboratory mill can be adjusted to give reliable milling quality data for 100g samples. Similarly, the Brabender Quadrumat Junior mill is modified to allow an estimate of soft wheat milling quality for 20g samples.

Automatic laboratory mills provide reliable results, even when used by relatively inexperienced operators. The most commonly used continuous experimental mills are the previously described Brabender Quadrumat Junior experimental mill and the Buhler laboratory mill.

The modern version of Buhler laboratory mill use pneumatic conveyors. The Buhler laboratory mill has a simple flow comprising only three breaks and three reductions. The three-break passages are built on one roll pair and the three reduction passes are built on a second roll pair. The reduction rolls may be either smooth or corrugated. The capacity of the mill is generally more than 100 g/min. Buhler laboratory mill can produce a straight-grade flour comparable in quality to commercial flour. The flour extraction rate of the Buhler laboratory mill is generally less than of commercial extraction rates. Laboratory mills should be adjusted so as commercial flour extraction rates should be achieved to correctly evaluate the commercial potential of wheat. With minor modifications to the Buhler mill it is possible to achieve commercial flour extraction rates.

Manual mills consist of at least one roll stand and sifter. Feed is added manually. These mills have the advantage of flexibility, but they require skilled operators to achieve consistent results. Batch mill roll gaps and speeds are adjustable, but better precision of milling results can be achieved by using several roll stands with fixed settings. Sieving is generally performed on a multisieve laboratory box sifter. Sieves are removed and changed as the milling progresses. Purifiers are usually not used in experimental flour milling.

There are several advantages to using a batch system for experimental milling. First, the miller has an opportunity to examine the distribution and visual quality of stock throughout the millflow, thereby gaining considerable insight into wheat milling properties. Next, a batch milling system allows the miller to vary the milling procedure according to the quantity and quality of flour required and the nature of the wheat, by adjusting roll settings. Furthermore, batch mill roll stands are valuable research tools for examining the influence of grinding conditions on wheat milling performance and flour quality. Finally, batch mills are also particularly useful for durum wheat semolina milling. The experimental mills described here provide valuable milling information, but they cannot satisfactorily simulate commercial milling. Therefore, pilot scale mills have been designed to bridge this gap. Ideally, pilot mills retain sufficient flexibility to permit large-scale experimentation with a variety of commercial millflows, thereby providing a vehicle for testing experimental results obtained with small-scale laboratory mills.

4.5 INTERPRETATION OF RESULTS

It is important to analyze and interpret the data obtained on experimental laboratory mills for meaningful application of the milling results. Interpretation of milling data is useful to find solution to a simple or complex problem. Experimental milling results are useful in assessing milling quality of wheat varieties. Some of the approaches that have been used to evaluate experimental milling data are described in this section.

Several factors besides flour extraction rate determine the milling value of wheat. For example, the lower the flour ash and the brighter the flour color, the more desirable is the wheat for milling. Following formula is used for calculating wheat-milling value on the basis of straight-grade flour ash:

$$\text{Milling rating} = \%\ \text{extraction} - (\text{ash} \times 100)$$

In the United Kingdom, where flour colour is an important measure of flour quality, the following formula is used for assessing milling value of wheat:

$$\text{Milling value} = \%\ \text{extraction} - \text{Kent-Jones flour color}$$

Cumulative ash curves are also widely used for assessing comparative milling quality of different wheats. Cumulative ash curves are generated, as in commercial milling, by arranging millstreams in ascending order of ash on a constant moisture basis and tabulating cumulative ash and cumulative extraction for each successive millstream. Wheats that exhibit the lowest initial flour ash and the slowest rate of ash increase with increasing flour extraction are preferred because they produce the highest proportion of patent flour.

The behaviour of wheat during milling and stock distribution is also linked to wheat milling performance. A high yield of break flour and fine flour particle size is associated with better cake and cookie quality for soft wheats. The ease with which endosperm can be separated from bran flakes, is widely known as the "milling separation index", is also associated with soft wheat milling quality. Cleanliness, wheat moisture, more tolerance to tempering water and feed rate are also important factors that have a direct bearing on the milling value of wheat.

4.6 MODEL PREDICTING MILLING YIELD OF WHEATS

The following equation models can predict the flour yield of wheat varieties:

Flour yield (Hard wheat) = 36.2 – 0.30 TKW + 17.4 KW – 0.26 TW

Flour yield (Soft wheat) = 113.0 + 0.15 KL – 0.68 TW

Where, TKW = 1000-kernel weight; KW = kernel width; TW = test weight and KL = kernel length. These parameters can easily be measured in any laboratory. The above equations provide a correlation coefficient of r = 0.72 and 0.56 between measured and predicted flour yields for hard and soft wheat, respectively as shown in **Figure 4.1**.

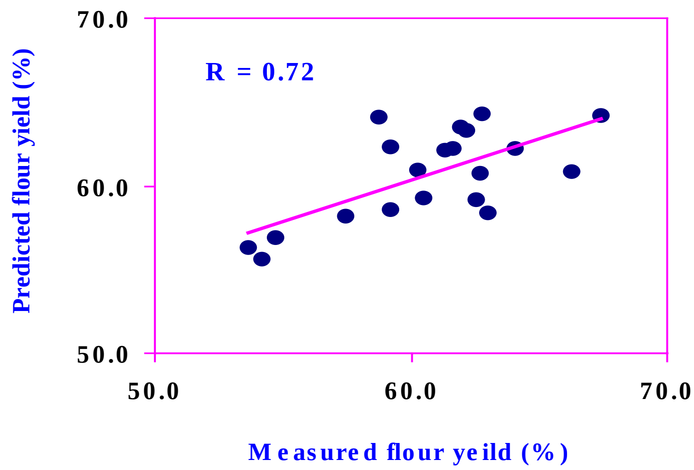

Figure 3. Correlation between measured and predicted flour yield

4.7 SUMMARY

Experimental or laboratory wheat milling is a general term referring to milling procedures conducted on small scale under strict control. Experimental milling data is found useful in the evaluation of lines from wheat breeding programs, prediction of the end-use quality of commercial samples, and research investigations. Many commercial flourmills use experimental milling to monitor mill performance and to obtain advance information on the properties of incoming wheat shipments. Experimental milling equipment is available commercially in numerous shapes and sizes. The most commonly used commercially available laboratory mills is the Brabender Quadrumat Junior and Senior mills. In recent years milling operations have been automated and computerized. These developments have been induced for precise and simple monitoring of plant operation, flour yields, and for rapid generation of production reports. These measurements are achieved largely through the use of microprocessor-based controllers/sensors.

4.8 KEY WORDS

Air classification: It is a physical separation of flour into fractions of higher protein and starch contents. The separation is achieved based on particle size and density.

Experimental wheat milling: It is a general term referring to milling procedures conducted on small scale under strict control.

Tempering : It refers to the process of adjustment of the moisture level of wheat grains before milling. This is carried out at room temperature. It requires 18-72 hours for grains to attain moisture equilibrium.

Milling rating: A formula is used for calculating wheat-milling value on the basis of straight-grade flour ash: Milling rating = % extraction – (ash × 100)

Milling separation index: The ease with which endosperm can be separated from bran, is widely known as the "milling separation index".

4.9 SELF ASSESSMENT QUESTIONS

1. What is the advantage of air classification technique in wheat milling?
2. Discuss advances that have been made in tempering of wheat grains.
3. How automation of milling machinery helps in improving milling operation?
4. Discuss the automation of milling machinery.

5. What precautions should be taken prior to and during experimental milling?

6. Why experimental milling is practiced?

7. Describe the procedure of experimental milling and also give a brief account of laboratory mills commonly used in research laboratories for assessing milling potential of wheat varieties.

8. How milling results are interpreted for the purpose of evaluating the milling quality of wheats?

4.10. SUGGESTED READINGS

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