Course Title: Cereal Processing
Course No: FDST 214
Credits: 3(2+1)

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Theory Lecture Outlines

1. Present status and future prospects of cereals and millets - Current trends in area, production and yield
2. Structure of cereals - Wheat, Corn, Rice, Barley, Oat, Rye and Sorghum
3. Composition and nutritive value of cereals. Physico-chemical properties of cereals, major and minor millets - Bulk density, True density, Porosity, Sphericity, Roundness, 1000 grain weight, Coefficient of friction and Angle of repose
4. Thermal properties - Specific heat - Thermal Conductivity - Thermal diffusivity
5. Theory of grain drying - Thin layer drying - Moisture content - Moisture measurement - Direct and indirect methods
6. Equilibrium moisture content (EMC) - Determination of EMC - EMC models - Hysteresis - Bound, unbound and free moisture
7. Drying curves - Constant rate period and falling rate period - Deep bed drying - Problems on moisture content
8. Methods of grain drying - Conduction, Convection, Radiation, Dielectric, Chemical and Sack drying
9. Grain dryers - Unheated and heated air dryers - Batch and continuous type - Flat bed type - PHTC type - Columnar type - LSU type - Baffle type - Rotary type
11. Rice milling - Traditional rice milling machinery - Engelberg huller, Huller mill, Battery of hullers, Sheller cum huller mill, Sheller mill, Sheller cum cone polisher mill
12. Modern rice milling process - Cleaning, Dehusking, Husk separation, Paddy separation, Polishing and Grading operations and their related equipments
13. Advantages and disadvantages of milling machineries - Factors that affect rice out turn during milling
14. By-products of rice milling - Rice bran, rice hulls, broken grains, rice pollards
15. Parboiling of paddy and its principle - Physico-chemical changes during parboiling – Steps in parboiling - soaking, steaming and drying
16. Effect of parboiling on milling, nutritional and cooking quality of rice.
17. Advantages and disadvantages of parboiling
18. Methods of parboiling of paddy - Traditional methods - Atapa, Balam, Josh, Sela and Siddha processes
19. Parboiling - single boiling and double boiling methods - Improved methods - CFTRI method - Schule process - Crystal rice process
22. Sodium chromate method - Brine solution method - Kisan continuous parboiling method - Pressure parboiling method
23. Ageing of rice - Enrichment of rice
24. Rice fortification - Methods of rice fortification
25. Processed products from rice - Rice flour - Parched rice - Puffed rice - Flaked rice - Rice starch - Instant rice - Canned rice
26. Wheat - Types of wheat - Wheat quality and grading
27. Wheat flour milling - Components of a wheat mill
28. Corn dry milling and wet milling - Products of corn milling
29. Milling of Barley, Oats and Rye
30. Milling of Sorghum, Bajra, Ragi - Their food uses
31. Malting of cereals - Uses of malt
32. Breakfast cereal foods - Flaked breakfast cereals, puffed breakfast cereals, shredded and granular breakfast cereals and cereals puffed by extrusion
Lecture-1
Present status and Future prospects of cereals and millets

For four consecutive years from 2005-06 to 2008-09, food grains production registered a rising trend and touched a record level of 234.47 million tonnes in 2008-09. The production of food grains declined to 218.11 million tonnes during 2009-10 (final estimates) due to the long spells of drought in various parts of the country in 2009. The productivity of almost all the crops suffered considerably, which led to decline in their production in 2009. As per the second advance estimates released by Ministry of Agriculture on 9.2.2011, production of foodgrains during 2010-11 is estimated at 232.07 million tonnes compared to 218.11 million tonnes last year (Table). This is only marginally below the record production of 234.47 million tonnes of food grains in 2008-09. The country is likely to achieve record production of wheat (81.47 million tonnes), pulses (16.51 million tonnes) and cotton (33.93 million bales of 170 kg. each) this year. This high level of production has been achieved despite crop damage due to drought in Bihar, Jharkhand, Orissa and West Bengal and the effects of cyclones, unseasonal and heavy rains, and cold wave and frost conditions in several parts of the country.

Rice and wheat: During the 1980s the growth in area in rice was marginal at 0.41 per cent but growth in production and yield was above 3 per cent. From 2000-01 to 2009-10 the situation changed with growth in area turning negative and in production and yield standing at 1.59 per cent and 1.61 per cent respectively. In wheat too, during the 1980s the growth in area was marginal at 0.46 per cent but in production and yield was above 3 per cent. During 2000-01 to 2009-10 the growth in area in wheat was 1.21 per cent and in production and yield was 1.89 per cent and 0.68 per cent respectively. This suggests that in these two crops the yield levels have plateaued and there is need for renewed research to boost production and productivity. Given the constraints in area expansion, there is no other alternative. Both public and private-sector investment in research and development (R&D) needs to be encouraged.

Coarse Cereals: In coarse cereals the situation is totally different. Since there was no technological breakthrough in these crops, the growth rate in area of total coarse cereals, in both the periods (1980-81 to 1989-90 and 2000-01 to 2009-10) was negative reflecting either shift to other crops or relatively dry area remaining fallow. In all the major coarse cereals there was negative growth in area during both the periods except for maize, which recorded a growth rate of 2.98 per cent in the 2000-01 to 2009-10 period. However, growth in production and yield for coarse grains which was 0.40 per cent and 1.62 per cent respectively in the 1980s improved significantly to 2.46 per cent and 3.97 per cent respectively in the 2000-01 to 2009-10 period. This increase is primarily driven by maize and bajra. Special effort is required to promote production and productivity of all coarse cereals to ensure food security.

The food and nutritional security of India currently depends to a great extent on the production of wheat and rice. These two crops together constituted 78 per cent of total food grains production in 2009-10, whereas coarse cereals constitute only 15 per cent in the same year. The area under coarse cereals has shown a decline over the years whereas their yield has shown significant improvement despite decrease in area in all the major coarse cereals except maize. The nutritional value of coarse cereals is also gradually
being realized. There is every reason to promote the production of these crops and help them realize their full potential with increased investment in research and schemes to promote their cultivation particularly in rain-fed areas.

### Table 1: Agricultural Production 2010-11

<table>
<thead>
<tr>
<th>Crops</th>
<th>2nd Advance Estimates 2010-11</th>
<th>Target 2010-11</th>
<th>Percentage of 2010-11 production to target set for 2010-11</th>
<th>2009-10 (final estimates)</th>
<th>Percentage change in 2010-11 compared to 2009-10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>94.01</td>
<td>102.00</td>
<td>92.17</td>
<td>89.09</td>
<td>5.52</td>
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<tr>
<td>Wheat</td>
<td>81.47</td>
<td>82.00</td>
<td>99.35</td>
<td>80.80</td>
<td>0.83</td>
</tr>
<tr>
<td>Coarse Cereals</td>
<td>40.08</td>
<td>44.00</td>
<td>91.09</td>
<td>33.55</td>
<td>19.46</td>
</tr>
<tr>
<td>Pulses</td>
<td>15.51</td>
<td>15.50</td>
<td>100.06</td>
<td>14.66</td>
<td>12.62</td>
</tr>
<tr>
<td>Total Foodgrains</td>
<td>232.07</td>
<td>244.50</td>
<td>94.92</td>
<td>218.11</td>
<td>6.40</td>
</tr>
<tr>
<td>Oilseeds</td>
<td>27.85</td>
<td>33.20</td>
<td>83.89</td>
<td>24.88</td>
<td>11.94</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>336.70</td>
<td>315.00</td>
<td>106.89</td>
<td>292.30</td>
<td>15.19</td>
</tr>
<tr>
<td>Cotton*</td>
<td>33.93</td>
<td>26.00</td>
<td>130.60</td>
<td>24.22</td>
<td>40.09</td>
</tr>
<tr>
<td>Jute and Mesla**</td>
<td>10.08</td>
<td>11.50</td>
<td>87.65</td>
<td>11.82</td>
<td>-14.72</td>
</tr>
</tbody>
</table>

Notes: * million bales of 170 kg each  
** million bales of 180 kg each

### Table 2: Compound Growth Rates of Area, Production and Yield

<table>
<thead>
<tr>
<th>Crop</th>
<th>1980-81 to 1989-90</th>
<th>2000-01 to 2009-10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area</td>
<td>Production</td>
</tr>
<tr>
<td>Rice</td>
<td>0.41</td>
<td>3.62</td>
</tr>
<tr>
<td>Wheat</td>
<td>0.46</td>
<td>3.57</td>
</tr>
<tr>
<td>Jowar</td>
<td>-0.99</td>
<td>0.28</td>
</tr>
<tr>
<td>Bajra</td>
<td>-1.05</td>
<td>0.03</td>
</tr>
<tr>
<td>Maize</td>
<td>-0.20</td>
<td>1.89</td>
</tr>
<tr>
<td>Ragi</td>
<td>-1.23</td>
<td>-0.10</td>
</tr>
<tr>
<td>Small millets</td>
<td>-4.32</td>
<td>-3.23</td>
</tr>
<tr>
<td>Barley</td>
<td>-6.03</td>
<td>-3.48</td>
</tr>
<tr>
<td>Total Coarse Cereals</td>
<td>-1.34</td>
<td>0.40</td>
</tr>
<tr>
<td>Total Cereals</td>
<td>-0.26</td>
<td>3.03</td>
</tr>
<tr>
<td>Gram</td>
<td>-1.41</td>
<td>-0.81</td>
</tr>
<tr>
<td>Tur</td>
<td>2.30</td>
<td>2.87</td>
</tr>
<tr>
<td>Other Pulses</td>
<td>0.02</td>
<td>3.05</td>
</tr>
<tr>
<td>Total Pulses</td>
<td>-0.09</td>
<td>1.52</td>
</tr>
<tr>
<td>Total Foodgrains</td>
<td>-0.23</td>
<td>2.85</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>1.44</td>
<td>2.70</td>
</tr>
<tr>
<td>Oilseeds</td>
<td>1.51</td>
<td>5.20</td>
</tr>
<tr>
<td>Cotton</td>
<td>-1.25</td>
<td>2.80</td>
</tr>
</tbody>
</table>
Lecture-2
Structure of Cereal Grains

The cereal crops that are grown for their edible fruit are generally called grain, but botanically referred to as caryopsis. The cereal seed consists of two major components, the endosperm and embryo or germ. The endosperm encompass the bulk of the seed and is the energy source of stored food. An outer wall called the pericarp that develops from the ovary wall encases the endosperm. A semi permeable layer under the pericarp, which is called testa, surrounds the embryo and is derived from the inner ovary wall. The testa is permeable to water, but not to dissolved salts, and is important for germination. The third layer, which is called aleurone, contains thick-walled cells that are free of starch. The pericarp, testa, and aleurone layer are collectively called the bran.

1. Wheat:
Wheat is a single-seeded fruit, 4- to 10-mm long, consisting of a germ and endosperm enclosed by an epidermis and a seed coat. The fruit coat or pericarp (45- to 50-μm thick) surrounds the seed and adheres closely to the seed coat. The wheat color, depending on the species and other factors, is red to white, and is due to material present in the seed coat. Wheat also is classified based on physical characteristics such as red, white, soft, hard, spring, or winter. The wheat kernel structure is shown in Fig.

![Diagram of Wheat Structure](Image)

**Fig. 1** Diagrammatic illustrations of wheat structure. (From Laszlo, 1999.)
The outer pericarp is composed of the epidermis and hypodermis. The epidermis consists of a single layer of cells that form the outer surface of the kernel. On the outer walls of the epidermal cells is the water-impervious cuticle. Some epidermal cells at the apex of the kernel are modified to form hairs. The hypodermis is composed of one to two layers of cells. The inner pericarp is composed of intermediate cells and cross-cells inward from the hypodermis. Long and cylindrical tube cells constitute the inner epidermis of the pericarp. In the crease, the seed coat joins the pigment strand, and together they form a complete coat about the endosperm and germ. Three layers can be distinguished in the seed coat: a thick outer cuticle, a "color layer" that contains pigment, and a very thin inner cuticle. The bran comprises all outer structures of the kernel inward to, and including, the aleurone layer. This layer is the outer layer of the endosperm, but is considered as part of the bran by millers. The aleurone layer is usually one cell thick and almost completely surrounds the kernel over the starchy endosperm and germ. The endosperm is composed of peripheral, prismatic, and central cells that are different in shape, size, and position within the kernel. The endosperm cells are packed with starch granules, which lie embedded in a matrix that is largely protein.

2. Corn

Corn or maize (Zea mays L.) is an important cereal crop in North America. Maize within a few weeks, develops from small seed to a plant, typically 2- to 3.5-m tall. Corn apparently originated in Mexico and spread northward to Canada and southward to Argentina. The corn seed is a single fruit called the kernel. It includes an embryo, endosperm, aleurone, and pericarp. The pericarp is a thin outer layer that has a protection role for the endosperm and embryo. Pericarp thickness ranges from 25 to 140 µm among genotypes. Pericarp adheres tightly to the outer surface of the aleurone layer and is thought to impart semi permeable properties to the corn kernel. All parts of the pericarp are composed of dead cells that are cellulosic tubes. The innermost tube-cell layer is a row of longitudinal tubes pressed tightly against the aleurone layer. This layer is covered by a thick and rather compact layer, known as the mesocarp, composed of closely packed, empty, elongated cells with numerous pits. A waxy cutin layer that retards moisture exchange covers an outer layer of cells, the epidermis. The endosperm usually comprises 82-84% of the kernel dry weight and 86-89% starch by weight. The outer layer of endosperm or the aleurone layer is a single layer of cells of an entirely different appearance. This layer covers the entire starchy endosperm. The germ is composed of the embryo and the scutellum. The scutellum acts as the nutritive organ for the embryo, and the germ stores nutrients and hormones that are necessary for the initial stage of germination. A typical longitudinal section of a kernel of corn is shown in Fig.
3. Rice

Rice (Oryza sativa L.) is one of the major food staples in the world. The ripe rice is harvested as a covered grain (rough rice or paddy), in which the caryopsis is enclosed in a tough hull or husk composed mostly from silica. The pericarp is fused to the seed and comprises seed coat, nucellus, endosperm, and embryo. The caryopsis is covered by hull, composed of two modified leaves: the palea and larger lemma. The hull provides protection for the rice caryopsis. The hull also protects the grain from insect infestation and fungal damage. The hull consists of four structural layers: (a) an outer epidermis of highly silicified cells; (b) sclerenchyma or hypoderm fibers two- or three-cell-layers thick; (c) crushed, spongy parenchyma cells; and (d) inner epidermis of generally isodiametric cells. The embryo or germ is very small and is located on the central side at the base of the grain. The typical structure of the rice grain is shown in Fig.
4. Barley

Barley (Hordeum vulgare L.) also belongs to the grass family and is one of the major ancient world's crops. It contributes to the human food, malt products, ranks the top ten crops, and is fourth among the cereals. In the commercial barley, the flowering glumes or husk is attached to the grain, whereas some varieties are hull-less and the grain is separate from the husk. The husk is usually pale yellow or buff and is made up of four types of cells, which are dead at maturity. The caryopsis is located in the husk and the pericarp is fused to the seed coat or testa. Within the seed coat the largest tissue is the starchy endosperm that is bonded to the aleurone layer. The embryo is located at the base of the grain. The longitudinal section of the mature barley is shown in Fig. 4.

![Fig. 4 Structure of the mature barley. (From MacGregor and Bhaty, 1993.)](image)

5. Oat

Oat is grown for both grain and forage needs. The hull contributes to about 30% of the total kernel weight. It consists of leaf-like structures that tightly enclose the groat and provide protection during seed growth. At the early stage of growth, the hull assists in nutrient transport and contributes significantly to groat nutrition. Contribution of hulls to the total dietary fiber content of oat is considerable; the hemicellulose content of the oat hull is between 30 and 50%. After removing the hulls, the morphology of remaining groat is not unlike other common cereals. The groat is longer and more slender than wheat and barley and, mostly, is covered extensively with hairs. The groat consists of three morphological and chemically distinct components: bran, germ, and starchy endosperm. These components are traditional descriptions of commercial fractions and do not accurately reflect the genetic, chemical, or fractional characteristics of each fraction. The structure of the oat kernel is shown in Fig.
6. Rye

Rye (Secale cereale L.), another member of the grass family, has two species: S. fragile and S. cereale. Rye is used mostly in bread making. The mature rye grain is a caryopsis, dry, one-seeded fruit, grayish yellow, ranging from 6 to 8 mm in length and 2 to 3 mm in width. The ripe grain is free-threshing and normally grayish yellow. The seed consists of an embryo attached-through a scutellum to the endosperm and aleurone tissues. These are enclosed by the remnants of the nuclear epidermis, the testa or seed coat, and the pericarp or fruit coat. The aleurone is botanically the outer layer of the endosperm and, in rye, is generally one-cell thick. The aleurone layer surrounds the starchy endosperm and merges into the scutellum located between the endosperm and embryo. In the mature grain, the aleurone is characterized by the presence of numerous intensely staining aleurone granules. The starchy endosperm represents the bulk of the kernel and is composed of three types of cells: peripheral or subaleurone, prismatic, and central, which differ in shape, size, and location within the kernel. The schematic of the longitudinal section of a rye cell is known in Fig
7. Sorghum

Sorghum (Sorghum bicolor L.) is a major source of energy and protein in developing countries, especially in Africa and Asia. The sorghum kernel is roughly spherical and is composed of three main components: the seed coat, embryo, and endosperm. The seed coats consist of the fused pericarp and testa. The extreme outer layer is pericarp that is surrounded by a waxy cuticle. Some sorghums contain a complete testa that may or may not contain spots of pigment. The embryo consists of a large scutellum, an embryonic axis, a plumule, and a primary root. The embryo is relatively firmly embedded and difficult to remove by dry milling. The endosperm is the largest proportion of the kernel and consists of an aleurone layer. The peripheral layer is made up of cells containing a high proportion of protein. The layer after the peripheral layer, called the corneous layer, contains less protein and a higher proportion of starch than the peripheral layer.

Figure shows the structure of a sorghum grain. The mature sorghum grain comprises about 10% embryo, 8% pericarp or bran layers, and 80% endosperm. These proportions may vary with variety, environmental condition, and degree of maturity. The embryo is rich in protein, lipid, minerals and B-vitamin groups.
Lecture-3 & 4
Composition and Nutritive value

Nutritive value of different cereals is given in table.

<table>
<thead>
<tr>
<th>Food</th>
<th>Energy Kcal</th>
<th>Protein g</th>
<th>Fat g</th>
<th>Carbohydrates g</th>
<th>Calcium mg</th>
<th>Iron mg</th>
<th>Carotene mg</th>
<th>Thiamine mg</th>
<th>Riboflavin mg</th>
<th>Niacin mg</th>
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<tbody>
<tr>
<td>Bajra</td>
<td>361</td>
<td>11.6</td>
<td>5.0</td>
<td>67.5</td>
<td>42</td>
<td>8.0</td>
<td>132</td>
<td>0.33</td>
<td>0.25</td>
<td>2.3</td>
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<td>Jowar</td>
<td>349</td>
<td>10.4</td>
<td>1.9</td>
<td>72.6</td>
<td>25</td>
<td>4.1</td>
<td>47</td>
<td>0.37</td>
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<tr>
<td>Maize, dry</td>
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<td>11.1</td>
<td>3.6</td>
<td>66.2</td>
<td>10</td>
<td>2.3</td>
<td>90</td>
<td>0.42</td>
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<td>24.6</td>
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<td>1.1</td>
<td>32</td>
<td>0.11</td>
<td>0.17</td>
<td>0.6</td>
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<td>Ragi</td>
<td>328</td>
<td>7.3</td>
<td>1.3</td>
<td>72.0</td>
<td>344</td>
<td>3.9</td>
<td>42</td>
<td>0.42</td>
<td>0.19</td>
<td>1.1</td>
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<td>77.4</td>
<td>10</td>
<td>2.8</td>
<td>9</td>
<td>0.27</td>
<td>0.12</td>
<td>4.0</td>
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<td>0.4</td>
<td>79.0</td>
<td>9</td>
<td>1.0</td>
<td>—</td>
<td>0.21</td>
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<td>3.2</td>
<td>2</td>
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<td>Rice, raw, milled</td>
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<td>0</td>
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<td>0.06</td>
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<tr>
<td>Wheat flour (whole)</td>
<td>341</td>
<td>12.1</td>
<td>1.7</td>
<td>66.4</td>
<td>48</td>
<td>4.9</td>
<td>29</td>
<td>0.49</td>
<td>0.17</td>
<td>4.3</td>
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<tr>
<td>Wheat flour (refined)</td>
<td>348</td>
<td>11.0</td>
<td>0.9</td>
<td>73.9</td>
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<td>2.7</td>
<td>25</td>
<td>0.12</td>
<td>0.07</td>
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<tr>
<td>Wheat bread (white)</td>
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<td>7.8</td>
<td>0.7</td>
<td>51.9</td>
<td>11</td>
<td>1.1</td>
<td>—</td>
<td>0.07</td>
<td>—</td>
<td>0.7</td>
</tr>
</tbody>
</table>


**Energy**: Cereals are the main source of energy, contributing 70-80% of the requirement.

**Carbohydrates**: 80% of dry matter of cereals is carbohydrate. The two carbohydrates present are crude fibre and soluble carbohydrate. The fibre constituents are cellulose, hemicellulose and pentosans. Of the soluble carbohydrate, starch is the most important carbohydrate in all cereals. Small quantities of dextrin and sugars are also present. Free sugars present include simple sugars such as glucose and disaccharides like sucrose and maltose. Of all the cereals, whole wheat, ragi and bajra contain high amount of fibre.

**Protein**:

The protein content of different cereals varies. Rice contains less amount of protein compared to other cereals. The protein content of different varieties of the same cereal also varies. Proteins are formed in all the tissues of the cereal grain. Higher concentrations occur in the embryo, scutellum and aleurone layer than in the endosperm, pericarp and testa. Within the endosperm the concentration of protein increases from the center to the periphery. The types of protein present in cereals are albumins, globulins, prolaminences (gliadins) and glutelins. The proportion of these proteins differ in different cereals. The gliadins and glutelins are known as gluten proteins. The gluten has unique elasticity and flow properties which are used for baking bread and other products.

Cereals contain 6-12% protein, which is generally deficient in lysine. They provide more than 50% of protein requirement as they are consumed in large quantities. Among cereals, rice protein is of better quality than the others. Cereals, when consumed with pulses, the protein quality improves due to mutual supplementation. Cereals are deficient in lysine and rich in methionine and rich in lysine. Hence there is improvement in protein quality of both proteins.
**Lipids:** Lipids are present to the extent of 1-2% in wheat and rice, and 3% in maize. More lipids are present in term and bran than in other parts of the grain. Wheat germ contains lipids 6-11% and bran 3-5% and endosperm 0.8-1.5%. Lipid content of maize germ is 35% and the bran contains 1%. The lipids are mostly the triglycerides of palmitic, oleic and linoleic acid. Cereals also contain phospholipids and lecithin.

Considering the amount of cereal consumed it is estimated that fat present in cereals in our diets can meet more than 50% of our essential fatty acid requirement. Cereals together with pulses can nearly meet the essential fatty acid requirement of an adult.

**Minerals:** About 95% of minerals are the phosphates and sulphates of potassium, magnesium and calcium. A considerable part of phosphorus in cereals is present in the form of phytin. Phosphorus and calcium present in phytin are not available for absorption. Phytates present in cereals decrease the absorption of iron. Unrefined cereals contain more phytates than refined or polished cereals. On germination of the grains, the phytate content reduces due to enzymatic breakdown and iron availability is improved.

Some mineral elements like copper, zinc and manganese are also present in very small quantities in cereals. Cereals are poor sources of calcium and iron particularly rice is a very poor source of these two elements. The content depends upon the extent of polishing. Ragi is a rich source of calcium and iron. Millets (ragi, bajra, jowar) are rich in minerals and fibre. The iron content of wheat is increased during milling where iron rollers are used.

**Vitamins:** Whole grain cereals are an important source of B vitamins in our diet. Since most of these vitamins are in the outer bran, refining or polishing the grains reduce B vitamin content. Parboiling which includes soaking in water and steaming of paddy results in seeping of vitamins present in outer layer into the grain. Hence milled and polished parboiled rice retains much of the B vitamins. Maida has less B vitamins than whole wheat flour.

Cereals do not contain either vitamin A or C except maize which contains small amount of carotenes. Oils from cereal grains are rich in vitamin E. Nutritive value of wheat and rice is compared in the Fig.

**Enzymes:** Certain grains contain many enzymes and of these the amylases, proteases, lipases and oxido-reductases are of importance. Upon germination α amylase activity increases. The proteases are relatively more in the germ. The lipases of the cereals are responsible for the fatty acids appearing during storage of the cereals and their products.

**Physical Properties of Cereals**

Data on physical properties of grain are essential for the design of equipment for handling, aeration, and storage as well as processing cereal grains and other agricultural
materials. Basic thermal and moisture transport properties are also required for simulating heat and moisture transport phenomena during drying and storage. The most important such properties are the grain weight, sphericity, roundness, size, volume, shape, surface area, bulk density, kernel density, fractional porosity, static coefficient of friction against different materials and angle of repose, heat capacity, thermal conductivity, thermal diffusivity, moisture diffusivity, equilibrium moisture content, and latent heat of vapourization. These properties vary widely, depending on moisture content, temperature and density of cereal grains.

1000-Grain weight: In handling and processing of grains, it is customary to know the weight of 1000 grain kernels. The 1000 grain weight is a good indicator of the grain size, which can vary relative to growing conditions and maturity, even for the same variety of a given crop. When compared with other crops at the same moisture level, the 1000 kernel weight will also provide an idea of relative size of the kernel for handling purposes. Generally, this is measured directly by taking the weight of 1000 grain kernels.

Sphericity and Roundness: Accurate estimation of shape-related parameters is important for determination of terminal velocity, drag coefficient and Reynolds number. It is also important to know the shape before any heat or moisture transport analysis can be performed. Sphericity is defined as the ratio of the surface area of a sphere, which has the same volume as that of the solid, to the surface area of the solid. Roundness of a solid is a measure of the sharpness of its corners and is defined as the ratio of the largest projected area of an object in its natural rest position to the area of the smallest circumscribing circle. Higher values of sphericity and roundness indicate that the objects’s shape is closer being spherical. The following relation is used for the calculation of sphericity and roundness of the grain:

\[
Sphericity = \frac{d_i}{d_c}
\]

\[
Roundness = \frac{A_p}{A_c}
\]

where \(d_c\) and \(A_c\) represent the diameter and area of the smallest circumscribing circle, respectively, \(d_i\) denotes the diameter of the largest inscribing circle. \(A_p\) is the projected area of the grain.

Bulk Density: The bulk density of cereal grains is determined by measuring the weight of a grain sample of known volume. The grain sample is placed in a container of regular shape, and the excess on the top of the container is removed by sliding a string or stick along the top edge of the container. After the excess is removed completely the weight of the grain sample is measured. The bulk density of the grain sample is obtained simply by dividing the weight of the sample by the volume of the container. The bulk density gives a good idea of the storage space required for a known quantity of particular grain. Bulk
density also influences the effective conductivity and other transport properties. From the storage point of view, it is important to determine the effect of moisture content on the bulk density of grains because the bulk density of some grains increase with an increasing moisture content, whereas it decreases for some other grains.

**Kernel density:** The kernel (true) density of grain is defined as the ratio of the mass of a grain sample to the solid volume occupied by the sample. For the determination of kernel density of an average grain, two methods have been suggested: one involved the displacement of a gas, whereas the other used displacement of a liquid. In both methods, Archimedes' principle of fluid displacement is used to determine the volume.

**Porosity:** It is defined as the percentage of volume of inter-grain space to the total volume of grain bulk. The porosity of grain is an important parameter that affects the kernel hardness, breakage susceptibility, milling, drying rate, and resistance to fungal development. Porosity depends on (a) shape, (b) dimensions and (c) roughness of the grain surface.

Porosity \( P \) is a property of grain that depends on its bulk and kernel densities. The grain porosity can be measured with the help of an air comparison pycnometer or by the mercury displacement method.

\[
P_f = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100
\]

where \( \rho_b \) = bulk density of grain \((\text{kg/m}^3)\) and \( \rho_t \) = kernel density of grain \((\text{kg/m}^3)\).

The porosity of grains varies with moisture content.

**Angle of Repose:**
The flowing capacities of different grains are different. It is characterized by the angle of natural slope. The angle of repose is the angle between the base and the slope of the cone formed on a free vertical fall of the grain mass to a horizontal plane.

**Coefficient of Friction:** The coefficient of friction between granular materials is equal to the tangent of the angle of internal friction for the material. The Static and dynamic coefficients of friction of grains on metals, wood, and other materials are needed for the design and prediction of grain motion in harvesting and handling equipment. These parameters are also important in determining the pressure of grain and silage against bin walls and silos. The frictional co-efficient depends on (a) grain shape, (b) surface characteristics and (c) moisture content.
Thermal Properties

The raw foods are subjected to various types of thermal treatment namely heating, cooling, drying, freezing etc., for processing. The change of temperature depends on the thermal properties of the product. Therefore knowledge of thermal properties namely, specific heat, thermal conductivity, thermal diffusivity is essential for the design of different thermal equipments and for solving various problems on heat transfer operation.

Specific Heat:
Specific heat of a substance is defined as the amount of heat required to raise the temperature of unit mass through 1 °C. In mathematical form, specific heat $C_p$, is written as $C_p = \frac{Q}{m \cdot dT}$ where $Q$ is the amount of heat, $m$ is the mass of material, and $dT$ is the change in temperature.

Thermal Conductivity:
The thermal conductivity is defined as the amount of heat flow through unit thickness of material over an unit area per unit time for unit temperature difference.

Thermal diffusivity:
Thermal diffusivity indicates how fast heat can penetrate through the material under transient condition of heat-transfer conditions. Physically it relates the ability to conduct heat with its ability to store heat. The thermal diffusivity can be calculated by dividing the thermal conductivity by the product of specific heat and mass density.

Lecture-5
Theory of Grain Drying

Generally the term drying refers to the removal of relatively small amount of moisture from a solid or nearly solid material by evaporation. Therefore, drying involves both heat and mass transfer operations simultaneously. In convective drying the heat required for evaporating moisture from the drying product is supplied by the external drying medium, usually air. Because of the basic differences in drying characteristics of grains in thin layer and deep bed, the whole grain drying process is divided into thin layer drying and deep bed drying.

Thin layer drying
Thin layer drying refers to the grain drying process in which all grains are fully exposed to the drying air under constant drying conditions, i.e., at constant air temperature, and humidity. Generally, up to 20cm thickness of grain bed (with a recommended air-grain ratio) is taken as thin layer. All commercial flow dryers are designed on thin layer drying principles.
Moisture content

Usually the moisture content of a substance is expressed in percentage by weight on wet basis. But the moisture content on dry basis is more simple to use in calculation as the quantity of moisture present at any time is directly proportional to the moisture content on dry basis.

The moisture content, \( m \), per cent, wet basis is:

\[
m = \frac{W_m}{W_m + W_d} \times 100
\]

where \( W_m \) = weight of moisture and \( W_d \) = weight of bone dry material,

The moisture content, \( M \), dry basis, percent is :

\[
M = \frac{W_m}{W_d} \times 100 = \frac{m}{100 - m} \times 100
\]

Moisture measurement

Moisture content can be determined by direct and indirect methods. Direct method includes air-oven drying method (130± 2\(^0\)C) and distillation method. Direct methods are simple and accurate but time consuming whereas indirect methods are convenient and quick but less accurate.

Direct methods

The air-oven drying method can be accomplished in a single stage or double stage in accordance with the grain samples containing less than 13 per cent or more than 13 per cent moisture content.

**Single stage method**

Single stage method consists of the following steps:

a) Grind 2-3 gm sample
b) Keep the sample in the oven for about 1 hour at 130± 2\(^0\)C.
c) Place the sample in a dessicator and then weigh. The samples should check within 0.1 per cent.

**Double stage method**

a) In this method keep 25-30 gm whole grain sample in the air oven at 130± 2\(^0\)C for 14-16 hours so that its moisture content is reduced to about 13 per cent.
b) Then follow the same procedure as in single stage method.

**Other methods**

Place the whole grain sample in the air-ooven at 100± 2\(^0\)C for 24-36 hours depending on the type of grain and then weigh.

The vacuum oven drying method is also used for the determination of moisture content.
However, moisture determination should be made according to the standard procedure for each grain which is laid down by the Government or by the Association of Agricultural Chemists.

**Brown –Duvel distillation method**

The distillation method directly measures the volume of moisture, in cc condensed in a measuring cylinder by heating a mixture of 100gm grain and 150cc oil in a flask at 200°C for 30 to 40 minutes. Moisture content can be measured by the toluene distillation method also.

**Indirect methods**

Indirect methods are based on the measurement of a property of the grain that depends upon moisture content. Two indirect methods are described as follows:

**Electrical resistance method**

Resistance type moisture meter measures the electrical resistance of a measured amount of grain sample at a given compaction (bulk density) and temperature. The electrical resistance varies with moisture, temperature and degree of compaction. The universal moisture meter (U.S.A), Tag-Happenstall moisture meter (U.S.A) and Kett moisture meter (Japan) are some of the resistance type moisture meters. They take only 30 seconds for the moisture measurement.

**Dielectric method**

The dielectric properties of grain depend on its moisture content. In this type of moisture meter, 200gm grain sample is placed between the condenser plates and the capacitance is measured. The measured capacitance varies with moisture, temperature and degree of compaction. The Motomco moisture meter (USA) and Burrows moisture recorder (USA) are some of the capacitance type moisture meters. They take about 1 minute for the measurement of moisture. These are also known as safe crop moisture testers as they do not damage the grain sample.
Lecture-6
Equilibrium Moisture Content

When a solid is exposed to a continual supply of air at constant temperature and humidity, having a fixed partial pressure of the vapour, \( p \), the solid will either lose moisture by evaporation or gain moisture from the air until the vapour pressure of the moisture of solid equals \( p \). The solid and the gas are then in equilibrium, and the moisture content of the solid in equilibrium with the surrounding conditions is known as equilibrium moisture content E.M.C (Fig).

The E.M.C is useful to determine whether a product will gain or lose moisture under a given set of temperature and relative humidity conditions. Thus E.M.C is directly related to drying storage. Different materials have different equilibrium moisture contents. The E.M.C is dependent upon the temperature and relative humidity of the environment and on the variety and maturity of the grain. A plot of the equilibrium relative humidity and moisture content of a particular material at a particular temperature (usually \( 25^\circ\text{C} \)) is known as equilibrium moisture curve or isotherm. Grain isotherms are generally S-shaped and attributed to multi – molecular adsorption.

**Determination of Equilibrium moisture content**

Generally E.M.C is determined by two methods: a) the static method, and b) the dynamic method. In the static method, the grain is allowed to come to equilibrium with surrounding still air without any agitation, whereas in the dynamic method, the air is generally mechanically moved. As the static method is time consuming, at high relative humidities mould growth in the grain may take place before equilibrium is reached. The dynamic method is faster and is thus preferred. The E.M.C. is to be determined under constant relative humidity and temperature conditions of air. Generally a thermostat is used to control the temperature and aqueous acid or salt solutions of different concentrations are used to control the relative humidity of air.
E.M.C Models:

A number of E.M.C equations namely BET equation (1938), Harkin and Jura equation (1944), Smith equation (1947), Henderson equation (1952), Chung and Fost equation (1967), have been developed for different ranges of relative humidities. A few purely empirical E.M.C equations namely Haynes equation (1961), Baker and Arkema equation (1974) etc., have also been proposed for different ranges of relative humidities for different cereal grains. Of them Henderson’s equation is well known and discussed here:

Using Gibb’s adsorption equation, Henderson (1952) developed the following equation to express the equilibrium moisture curve mathematically:

\[
1 - RH = \exp[-cTM_e^n]
\]

Where

- \( RH \) = equilibrium relative humidity, decimal
- \( M_e \) = E.M.C dry basis, per cent
- \( T \) = temperature, \(^\circ\)K and
- \( c \) and \( n \) = product constants, varying with materials

Hysteresis

Many solid materials including cereal grains exhibit different equilibrium moisture characteristics depending upon whether the equilibrium is reached by adsorption/sorption or desorption of the moisture. This phenomenon is known as hysteresis.

![Hysteresis Diagram](image)

Bound moisture

This refers to the moisture contained by a substance which exerts equilibrium vapour pressure, less than that of the pure liquid at the same temperature. The bound moisture may be contained inside the cell walls of the plant structure, moisture in loose chemical combination with the cellulosic material, moisture held in small capillaries and crevasses throughout the solid.

Unbound moisture

This refers to the moisture contained by a substance which exerts equilibrium vapour pressure equal to that of the pure liquid at the same temperature.

Free moisture

Free moisture is the moisture contained by a substance in excess of the equilibrium moisture, \( X - X_E \). Only free moisture can be evaporated and the free water content of a solid depends upon the vapour concentration in the air.
Lecture-7
Drying Curves

The plots of moisture content versus drying time or drying rate versus drying time or drying rate versus moisture content are known as drying curves.

Constant-rate period

Some crops including cereal grains at high moisture content are dried under constant-rate period at the initial period of drying. Falling –rate period follows subsequently. As for example, wheat is dried under constant-rate period when its moisture content exceeds 72%.
In the constant-rate period the rate of evaporation under any given set of air conditions is independent of the solid and is essentially the same as the rate of evaporation from a free liquid surface under the same condition. The rate of drying during this period is dependent upon: a) difference between the temperature of air and temperature of the wetted surface at constant air velocity and relative humidity, b) difference in humidity between air stream and wet surface at constant air velocity and temperature, and c) air velocity at constant air temperature and humidity.

Falling-rate period

Cereal grains are usually dried entirely under falling-rate period.

The falling rate period enters after the constant drying rate period and corresponds to the drying cycle where all surface is no longer wetted and the wetted surface continually decreases, until at the end of this period the surface is dry. The cause of falling off in the rate of drying is due to the inability of the moisture to be conveyed from the center of the body to the surface at a rate comparable with the moisture evaporation from its surface to the surroundings.

The falling-rate period is characterized by increasing temperatures both at the surface and within the solid. Furthermore, changes in air velocity have a much smaller effect than during the constant rate period. The falling rate period of drying is controlled largely by the product and is dependent upon the movement of moisture within the material from the center to the surface by liquid diffusion and the removal of moisture from the surface of the product.

The falling rate period of drying often can be divided into two stages: a) unsaturated surface drying, and b) drying where the rate of water diffusion within the product is slow and is the controlling factor. Practically all cereal grains are dried under falling-rate period if their moisture contents are not very high.

Effects of different factors on the drying process

The drying rate is dependent upon many factors, namely air temperature, air flow rate, relative humidity, exposure time, types, variety and size of the grain, initial moisture content, grain depth etc., Of them first four factors are important drying process variables which have been discussed below. The effects of some of the factors are shown in figs.
Effect of air temperature
Simmonds et al. showed that the rate of drying of wheat was sharply dependent upon the temperature of air varying from 21 to 77°C. The rate of drying increases with the rise of air temperature. But the equilibrium moisture content falls as air temperature increases. These observations are true for other cereal grains also.

Effect of air velocity
It is generally assumed that the internal resistance to moisture movement of agricultural materials is so great when compared to the surface mass transfer resistance that the air rate past the particles has no significant effect on the time of drying or on the drying coefficient. Henderson and Pabis found that air rate had no observable effect on thin layer drying of wheat when air flow was turbulent. According to them air flow rate varying from 10 cm³/sec/cm² to 68 cm³/sec/cm² had no significant effect on the drying rate of wheat. But in cases of paddy and corn it has been found that air rate has some effect on rate of drying.
**Effect of air humidity**
When the humidity of the air increases the rate of drying decreases slightly. The effect, however, is much smaller in comparison to the effect of temperature changes.

**Effect of air exposure time**
In the case of intermittent drying, drying rate of grain depends on its exposure time to the drying air in each pass. The total drying time which is the sum of all exposure times, is dependent upon exposure time. Total drying time reduces as exposure time decreases.

**Deep bed drying**
In deep bed drying all the grains in the dryer are not fully exposed to the same condition of drying air. The condition of drying air at any point in the grain mass changes with time and at any times it also changes with depth of the grain bed. Over and above the rate of air flow per unit mass of grain is small compared to the thin layer drying of grain. All on farm static bed batch dryers are designed on deep bed drying principle. The condition of drying in deep bed is shown in fig.

![Diagram of deep bed drying](image)

The drying of grain in a deep bin can be taken as the sum of several thin layers. The humidity and temperature of air entering and leaving each layer vary with time depending upon the stage of drying, moisture removed from the dry layer until the equilibrium moisture content is reached. Little moisture is removed, rather a small amount may be added to the wet zone until the drying zone reaches it. The volume of drying zone varies with the temperature and humidity of entering air, the moisture content of grain and velocity of air movement. Drying will cease as soon as the product comes in equilibrium with the air.
PROBLEMS ON MOISTURE CONTENT

Solved problems on moisture content

1) Two tones of paddy with 22% moisture content on wet basis are to be dried to 13% moisture content on dry basis. Calculate the weight of bone dry products and water evaporated.

Solution:

Weight of bone dried sample = \( 2000 - \frac{2000 \times 22}{100} \)
= 1560 kg

moisture content on dry basis for 22% moisture on wet basis

\( = \frac{22}{100 - 22} \times 100 \)
= 28.2 per cent (d.b)

Therefore, water evaporated

= 1560 \times (0.282 - 0.13)
= 237.2 kg

Amount of dried product

= 2000 - 237.2
= 1762.8 kg

2) Determine the quantity of parboiled paddy with 40 per cent moisture content on wet basis required to produce 1 tonne of product with 12 per cent moisture content on wet basis. Work out the problem on wet basis and check the answer using dry basis.

Solution:

On wet basis: Weight of paddy with 12 per cent moisture on wet basis = 1 tonne.

Weight of bone dry paddy = \( 1 - \frac{12 \times 1}{100} \)
= 0.88 tonne.

Let x be the amount of water present in the paddy with 40 per cent moisture content.

Therefore,

\[ \frac{x}{0.88 + x} \times 100 = 40 \]
\[ x = \frac{40 \times 0.88}{60} = 0.587 \text{ tonne} \]

Therefore, quantity of paddy with 40 per cent moisture content on wet basis:

= 0.587 + 0.88
= 1.467 tonne
On dry basis:
40 per cent moisture content on wet basis = 66.66 per cent (d.b)
Similarly 12 per cent m.c (w.b) = 13.65 per cent (d.b)
Amount of moisture evaporated
\[ \text{Amount} = 0.88 \left( \frac{66.66 - 13.65}{100} \right) \]
\[ = 0.467 \text{ tonne} \]
Total weight of paddy should be 1+0.467=1.467 tonne

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Lecture-8
Methods of Grain Drying

According to the mode of heat transfer, drying methods can be divided into: (a) conduction drying, (b) convection drying and (c) radiation drying. There are other methods of drying also, namely, dielectric drying, chemical or sorption drying, vacuum drying, freeze drying etc.

Of them, convection drying is commonly used for drying of all types of grain and conduction drying can be employed for drying of parboiled grain.

**Conduction drying**

When the heat for drying is transferred to the wet solid mainly by conduction through a solid surface (usually metallic) the phenomenon is known as conduction or contact drying. In this method, conduction is the principal mode of heat transfer and the vaporized moisture is removed independently of the heating media. Conduction drying is characterized by:

a) Heat transfer to the wet solid takes place by conduction through a solid surface, usually metallic. The source of heat may be hot water, steam, flue gases, hot oil, etc.,
b) Surface temperatures may vary widely;
c) Contact dryers can be operated under low pressure and in inert atmosphere;
d) Dust and dusty materials can be removed very effectively; and
e) When agitation is done, more uniform dried product and increased drying rate are achieved by using conduction drying. Conduction drying can be carried out either continuously or batch wise. Cylinder dryers, drum dryers, steam tube rotary dryers are some of the continuous conduction dryers. Vacuum tray dryers, freeze dryers, agitated pan dryers are the examples of batch conduction dryers.

**Convection drying**

In convection drying, the drying agent (hot gases) in contact with the wet solid is used to supply heat and carry away the vaporized moisture and the heat is transferred to the wet solid mainly by convection. The characteristics of convection drying are:

a) Drying is dependent upon the heat transfer from the drying agent to the wet material, the former being the carrier of vaporized moisture;
b) Steam heated air, direct flue gases of agricultural waste, etc, can be used as drying agents;
c) Drying temperature varies widely;
d) At gas temperatures below the boiling point, the vapour content of the gas affects the drying rate and the final moisture content of the solid;
e) If the atmospheric humidities are high, natural air drying needs dehumidification; and
f) Fuel consumption per kg of moisture evaporated is always higher than that of conduction drying.

Convection drying is most popular in grain drying. It can be carried out either continuously or batch-wise. Continuous tray dryers, continuous sheeting dryers, pneumatic conveying dryers, rotary dryers, tunnel dryers come under the continuous system, whereas tray and compartment dryers, batch through circulation dryers are the batch dryers.

Convection drying can be further classified as follows:

Convection drying

Drying under Fluidized state
Drying under spouted bed condition
Drying under ordinary state

Natural / unheated air drying
air drying with supplemental heat
heated air drying

Pneumatic or fluidized bed drying:
When the hot gas (drying agent) is supplied at a velocity higher than the terminal velocity of the wet solid, the drying of the wet solid occurs in a suspended or fluidized state. This phenomenon is known as fluidized bed drying.

Drying may be carried out in a semi-suspended state or spouted bed condition also.

Generally, the convection drying is conducted under ordinary state, i.e, drying agent is supplied at a velocity much lower than the terminal velocity of the wet material.

In natural air drying, the unheated air as supplied by the nature is utilized. In drying with supplemental heat just sufficient amount of heat (temperature rise within 5 to 10°C) only, is supplied to the drying air to reduce its relative humidity so that drying can take place.

In heated air drying, the drying air is heated to a considerable extent.

The natural air drying and drying with supplemental heat methods which may require one to four weeks or even more to reduce the grain moisture content to safe levels, are generally used to dry grain for short term storage in the farm. Heated air drying is most useful when large quantity of grain is to be dried within a short time and marketed at once. It is used for both short and long term storage.

Comparative advantage and disadvantages of the three convective drying methods are given as follows:
Advantages:
1. Lowest initial investment and maintenance cost.
2. No fuel cost.
3. No fire hazard.
4. Least supervision.
5. Least mould growth compared to supplemental heat.

Disadvantages:
1. Very slow drying rate, drying period may be extended to several weeks.
2. Weather dependent
3. More drying space necessary in comparison to heated air drying.
4. Useful particularly for short-term storage in the farm.
5. Not useful for humid tropics.

Supplemental Heat Drying
Advantages
1. Lower cost of equipment and maintenance
2. Independent of weather
3. Requires less supervision.
4. Most efficient use of bin capacity.

Disadvantages
1. Fire hazard to a certain extent
2. Danger of accelerated mould growth.
3. Rate of drying is still low.
4. Useful particularly for short term storage in the farm.

Heated Air Drying
Advantages
1. Independent of weather.
2. Fast drying
3. High drying capacity per fan horse-power.
4. Used for both long and short-term storage of grains.

Disadvantages
1. Higher initial investment and maintenance cost.
2. Considerable fuel expenditure.
3. Danger of fire hazard
4. Requires skilled manpower for control of drying condition.
5. By direct firing with liquid fuel, the products may be contaminated with the flue gases.

Radiation drying
Radiation drying is based on the absorption of radiant energy of the sun and its transformation into heat energy by the grain. ‘Sun drying’ is the example of radiation drying.
Radiation drying can also be accomplished with the aid of special infra-red radiation generators, namely, infra-red lamps. Moisture movement and evaporation is caused by the difference in temperature and partial pressure of water vapour between grain and surrounding air. The effectiveness of sun drying depends upon temperature and relative humidity of the atmospheric air, speed of the wind, type and condition of the grain, etc.

**Sun Drying**

Sun drying is the most popular traditional method of drying. A major quantity of grain is still dried by the sun in most of the developing countries.

**Advantages**
1. No fuel or mechanical energy is required.
2. Operation is very simple.
3. Viability, germination, baking qualities are fully preserved.
4. Microbial activity and insect/pest infestation are reduced.
5. Labour oriented
6. No pollution.

**Disadvantages**
1. Completely dependent on weather
2. Not possible round the clock and round the year.
3. Excessive losses occur due to shattering, birds, rodents, etc
4. Requires specially constructed large floor area, restricting the capacity of mill to a certain limit.
5. The entire process is unhygienic.
6. Unsuitable for handling of large quantity of grain within a short period of harvest.

**Infra-Red Drying**

Infra-red rays can penetrate into the irradiated body to a certain depth and transformed into heat energy. Special infra-red lamps, or metallic and ceramic surfaces heated to a specified temperature by an open flame, may be used as generators of infra-red radiation.

**Advantages**
1. Small thermal inertia.
2. Simplicity and safety in operation of lamp radiation dryers.

**Disadvantages**
1. High expenditure of electric power.
2. Low utilization factor.

Radiation dryers have been used in many countries for drying the painted surfaces of machinery, and in the timber processing, textile industry and cereal grain and other food industries.

**Dielectric drying**

In dielectric drying, heat is generated within the solid by placing it in a fixed high frequency current. In this method, the substance is heated at the expense of the dielectric loss factor. The molecules of the substance, placed in a field of high frequency current
are polarized and begin to oscillate in accordance with the frequency. The oscillations are
accompanied by friction, and thus a part of the electrical energy is transformed into heat.
The main advantage of this method is that the substance is heated with extraordinary
rapidity.

The dielectric drying has now been in use in different industries such as timber,
plastics and cereal grain processing.

**Chemical drying**

Various chemicals such as sodium chloride, calcium propionate, copper sulphate,
ferrous sulphate, urea, etc, have been tried for the preservation of wet paddy. Of these,
common salt has been proved to be effective and convenient for arresting deteriorative
changes during storage. When wet paddy is treated with common salt, water is removed
from the rice kernel by osmosis. The common salt absorbs moisture from paddy but it
cannot penetrate into the endosperm through the husk layer. This is an unique property of
the paddy which has rendered the application of common salt preservation possible.

**Advantages**

1. It not only dries paddy but also reduces the damage due to fungal, microbial
   and enzymatic activities and heat of respiration.
2. It does not affect the viability of the grain.
3. The milling quality of paddy is stationary.
4. Loss of dry matter is negligible.
5. It does not affect the quality of rice bran.

**Disadvantages**

1. The moisture may be retained on the husk due to the presence of sodium
   chloride.
2. The useful life of gunny will be shortened.
3. The colour of husk changes to dark yellow.
4. The common salt treated paddy requires an additional drying subsequently.
5. Economy of the process has yet to be established.

**Sack drying**

This method is particularly suitable for drying of small quantity of seed to prevent
mixing of varieties and conserve strain purity and viability.

The grain bags are laid flat over holes cut on the floor of a tunnel system so that
heated air can be forced up through the grain from an air chamber underneath.

Usually an air temperature of 45°C with an air rate of 4m³/min at 3-4 cm static
pressure per bag of 60kg is used for fastest drying rate. The sacks are turned once during
the drying operation. The sack drying process involves higher labour cost.
Grain dryers can be divided into two broad categories, unheated air dryers and heated air dryers. Different types of grain dryers of both groups have been discussed in this chapter.

**Unheated air dryers**

Unheated or natural air drying is usually performed in the grain storage bin. That is why unheated air drying is also known as in-bin or in-storage drying.

Natural air drying is commonly used for on-farm drying for a relatively small volume of grains. Either full bin or layer drying system is employed in natural air drying. The period of drying for either system may be as long as several weeks depending on the weather. In layer drying, the bin is filled with a layer of grain at a time and drying is begun. After the layer is partially dried, other layers of grain are added periodically, perhaps daily with the continuation of drying until the bin is full and the whole grain mass is dried. In full-bin drying, a full bin of grain is dried as a single batch. Then the drying bin is used for storage purposes. The air flow rate provided is relatively low. Though natural air is supposed to be used, an air heating system should be kept so that supplemental heat may be supplied to the natural air during rainy seasons and during periods of high humidity weather and for highly moist grains. Natural air drying cannot be used if the ambient relative humidity exceeds 70 per cent. So also grains containing moisture higher than 20 per cent should not be dried with natural air.

Various types of unheated air dryers with different constructions, shapes, grain feeding and discharging mechanisms and aeration systems are available. Some of the common types of dryers are described here.

As in natural air drying the grain is aerated (for drying) and stored in the same unit, the complete installation simply consists of a storage unit equipped with ducts for air distribution and devices for air exhaustion and a blower.

**Storage unit**

Any shape of grain holding bin such as semi-circular, circular, square or rectangular and of any material like metal, wood, concrete, asbestos or mineral agglomeration can be used provided the bin is made moisture proof. Different types of units are shown in Fig:
Fig: Types of air distribution systems used in bin drying

Fig: An inexpensive, easily built crib for the mechanical drying of ear corn

Fig: High round crib with perforated walls

Fig: Rectangular metal bin dryer with crosswise air ducts
Fig: Rectangular metal bin dryer with cross wise air ducts

Fig: Most desirable ducting system

Fig: General purpose building for drying and storing of grain
Of the many types of bins used in grain drying some of the common types are described as follows:

a) A round metal bin

With false perforated floor, having 4.5 meters diameter and 3 meters height can hold about 25 tonnes of paddy. The bin is fitted with a cover at the top in such a way that only the exhaust air can escape through it but rain cannot enter into the bin. In some cases exhaust air is allowed to escape through the side walls of the dryer also. The round bins can also be made of concrete or ferrocement. They are usually constructed of several rings sealed together.

Rectangular or square bins fitted with false perforated floor or main duct and laterals are also in use.

b) A screen tunnel Quonset type storage unit

The unit is fitted with a central horizontal screen type duct and a special air outlet system near the top of each vertical wall.

The bins are generally made circular to ensure uniform distribution of air and avoid stagnant pockets. The quonset type has the same advantages in this respect as the cylindrical bin.

**Aeration system**

Both propeller and centrifugal types of blowers are used for aeration. Centrifugal blowers may have either forward-curved or backward-curved blades.

The air flow and static pressure requirements for different types of grains and for different depths of grains are to be followed as per recommended values.

**Air distribution system**

Sufficient care should be taken in selecting and designing the air distribution system so that air is uniformly distributed throughout the grain bulk and void pockets are avoided. There are four major systems of air distribution:

a) Perforated floor,

b) Central horizontal duct,

c) Main duct and laterals, and

d) Vertical slatted duct.

a) Perforated floor

The circular storage bin (Fig) can be fitted with the perforated false floor through which unheated air is blown. Though the system is suitable for small and medium sized round bins and for small depths of grain, it is used for large rectangular bins and for higher grain depths as well.

b) Central horizontal duct

This system is used in the quonset type units (Fig.). This type of duct with openings in the wall can distribute air more uniformly through the grain bulk.
c) Main duct and laterals

The system of main duct and laterals is most commonly used and is adopted in round, square and even rectangular bins (Figs.). The laterals are open at the bottom and raised off the floor of the bin so that the air can flow through the mass. The laterals are inverted V or U or rectangular in shape and are made of wood or steel or concrete or ferro-cement. The laterals are spaced in accordance with the size of the storage unit, quantity of grain to be aerated or dried and depth of the grain (Figs.)

In round bins the ducts can also be placed in the form of a ring on the bin floor.
d) Vertical ducts

This system consists of either a vertical slatted duct (Figs) or a central vertical perforated tube (Fig). The air is blown through the slots or perforations and is spread laterally through the grain mass.
Heated Air Dryers
Flat Bed Type Batch Dryer

This is a static, deep bed, batch dryer. This type of batch dryer is very simple in design and is most popular for on-farm drying in many countries.

Construction

The rectangular box type batch dryers are shown in Figs. The size of the dryer depends on the area of the supporting perforated screen on which the grain is placed. The holding capacity of these dryers ranges from 0.25 to 1 tonne/batch only. The horse power of the motor for the blower ranges from $\frac{1}{4}$ to 1. For convenience an oil burner can be used but for economy a husk fired furnace should be used for the supply of heat.
Operation

The grain is placed on the supporting screen and the heated air is forced through the deep bed of grain. After drying of grains to the desired moisture level, they are discharged manually. The temperature of the heated air should be limited to 45°C. The drying rate varies from 20 to 40 m³/min per 1000 kg of raw paddy depending on the initial moisture content.

Advantages

1) Fairly reasonable price
2) Intermittent drying can also be used.
3) Operation is very simple
4) It can be used for seed drying and for storage purpose also after drying.
5) It can be manufactured locally using various types of materials like steel sheet, wood piece etc.

Disadvantages

1. Rate of drying is slow.
2. Uneven drying which results in higher percentage of brokens in grains.
3. Holding capacity is small compared to flow dryers.

Recirculatory Batch Dryer (PHTC type)

This is a continuous flow non mixing type of grain dryer.

Construction

The dryer consists of two concentric circular cylinders made of perforated (2 mm dia) mild steel sheet of 20 gauge. The two cylinders are set 15 to 20 cm apart. These two cylinders are supported on four channel sections. The whole frame can be supported by a suitable foundation or may be bolted to a frame made of channel section. A bucket elevator of suitable capacity is used to feed and recirculate the grain into the dryer. A centrifugal blower blows the hot air into the inner cylinder which acts as a plenum. The hot air from the plenum passes through the grain moving downward by gravity and comes out of the outer perforated cylinder. A torch burner is employed to supply the necessary heat with kerosene oil as fuel. The designs of PHTC dryer for ½, 1 and 2 tonnes holding capacity are available. The PHTC dryer of 2 tonnes holding capacity developed at PHTC, IIT, Kharagpur, India is shown in fig.
Operation

The grain is fed to the top of the inside cylinder. While descending through the annular space from the feed end to the discharge end by gravity, the grain comes in contact with a cross flow of hot air. The exhaust air comes out through the perforations of the outer cylinder and the grain is discharged through the outlet of the hopper. The feed rate of grain is controlled by closing or opening the gate provided with the outer pipe of the discharge hopper. The grain is recirculated till it is dried to the desired moisture level.
Advantages

1. Price is reasonable.
2. Simplest design amongst all flow type dryers
3. Easy to operate
4. It can be used on the farm and rice mill as well.
5. Operating cost is low with husk fired furnace.
Disadvantages

1. Drying is not so uniform as compared to mixing type.
2. Perforations of the cylinders may be clogged with the parboiled paddy after using it for a long time.

Louisiana State University Dryer

This is a continuous flow-mixing type of grain dryer which is popular in India and the U.S.A.

Construction

It consists of 1) a rectangular drying chamber fitted with air ports and the holding bin, 2) an air blower with duct, 3) grain discharging mechanism with a hopper bottom, and 4) an air heating system.

1) Rectangular bin: Usually the following top square sections of the bin are used for the design of LSU dryer.

   i) 1.2m x 1.2m, ii) 1.5m x 1.5m, iii) 1.8m x 1.8m and iv) 2.1m x 2.1m

   the rectangular bin can be divided into two sections, namely top holding bin and bottom drying chamber.

2) Air distribution system: Layers of inverted V-shaped channels (called inverted V-ports) are installed in the drying chamber. Heated air is introduced at many points through the descending grain bulk through these channels. One end of each air channel has an opening and the other end is sealed. Alternate layers are air inlet and air outlet channels. In the inlet layers, the channel openings face the air inlet plenum chamber but they are sealed at the opposite wall, where as in the outlet layers, the channel openings face the exhaust but are sealed other side. The inlet and outlet ports are arranged one below the other in an offset pattern. Thus air is forced through the descending grain while moving from the feed end to the discharge end. The inlet ports consists of a few full size ports and two half size ports at two sides. All these ports of same size are arranged in equal spacing between them. The number of ports containing a dryer varies widely depending on the size of the dryer.

   Each layer is offset so that the top of the inverted V ports helps in splitting the stream of grain and flowing the grains between these ports taking a zigzag path.

   In most models, the heated air is supplied by a blower.
3) **Grain discharging mechanism:** Three or more ribbed rollers are provided at the bottom of the drying chamber which can be rotated at different low speeds for different discharge rates of grains. The grain is discharged through a hopper fixed at the bottom of the drying chamber. Causing some mixing of grain and air the discharge system at the base of the dryer also regulates the rate of fall of the grain.

4) **Air heating system:** The air is heated by burning gaseous fuels such as natural gas, butane gas, etc, or liquid fuels such as kerosene, furnace oil, fuel oil etc, or solid fuels like coal, husk, etc. Heat can be supplied directly by the use of gas burner or oil burner or husk fired furnace and indirectly by the use of heat exchangers. Indirect heating is always less efficient than direct firing system. However, oil fired burner or gas burners should be immediately replaced by husk fired furnace for economy of grain drying.

   The heated air is introduced at many points in the drier so as to be distributed uniformly through the inlet ports and the descending grain bulk. It escapes through the outlet ports.

   This type of dryer is sometimes equipped with a special fan to blow ambient air from the bottom cooling section in which the dried or partially dried warm grain comes in contact with the ambient air.

   In general, the capacity of the dryer varies from 2 to 12 tonnes of grain, but sometimes dryers of higher capacities are also installed. Accordingly power requirement varies widely.

   Recommended air flow rate is 60-70 m³/min/tonne of parboiled paddy and optimum air temperatures are 60°C and 85°C for raw and parboiled paddy respectively. A series of dryers can also be installed.

**Advantages**

1. Uniformly dried product can be obtained if the dryer is designed properly.
2. The dryer can be used for different types of grains.
Disadvantages
1. High capital investment
2. Cost of drying is very high if oil is used as fuel.

Baffle Dryer
This is a continuous flow mixing type of grain dryer (Fig.)

Construction
The baffle dryer consists of: 1) grain receiving bin, 2) drying chamber fitted with baffles, 3) plenum fitted with hot air inlet, 4) grain discharge control device and 5) hopper bottom. A number of baffles are fitted with the drying chamber to divert the flow and effect certain degree of mixing of grain. The two baffle plates with the outer and inner sides are set 20cm apart for the passage of the grain in the drying chamber. The dryer is made of mild steel sheet.

Operation
Grain is fed at the top of the receiving bin and allowed to move downward in a zigzag path through the drying chamber where it encounters a cross flow of hot air. On account of zigzag movement, a certain degree of mixing of grain takes place. The particularly dried grain discharged from the hopper bottom is recirculated by a bucket elevator until it is dried to the desired moisture level.

Some of the dryers are fitted with a large overhead bin at the top which acts as an overhead tempering bin. This type of tempering dryer is shown in fig.
Advantages
1. Uniformly dried product is obtained.

Disadvantages
1. Ratio of the volume of plenum to the total volume of the dryer is relatively high.
2. Grains on the baffle plates move slowly than that of other sections.
Other advantages and disadvantages are same as described in LSU dryer.

Rotary Dryer
This is continuous dryer (Fig) as it produces the final dried product continuously.

Horizontal rotary dryers of various designs have been developed by different countries for the drying of parboiled paddy. Some of them are fitted with external steam jacket and internal steam tubes as well. As parboiled paddy can stand high temperature without significant increase of cracks in grains, these dryers can be employed for rapid drying of parboiled paddy using temperatures as high as 100 to 110°C. In India, the Jadavpur University, Calcutta introduced a rotary dryer of 1 tonne/hr capacity for the drying of parboiled paddy. The construction and operation of the same dryer are described as follows.
Construction

It consists of a cylindrical shell 9.15m long and 1.22m in diameter, with 48 pairs of 5 cm and 3.75cm size steam pipes in two concentric rows inside the shell in combination with common steam inlet and condensate outlet fittings. The shell is equipped with six longitudinal flights of 9.15m long and 15.24cm wide for lifting and forward movement of the parboiled paddy towards the discharge end while it is being dried. Over the feed end breeching box there are feed hopper and screw conveyor with an adjustable sliding gate. The dryer is equipped with an air blower and a small steam tube heat exchanger for supplying heated air at the entrance of the feed end breeching box. The cylindrical shell of the dryer is rotated at 2 to 6 rpm by a motor through speed reduction gear, pulley and belt drive system.

Operation

The soaked and steamed paddy is fed to the dryer by the screw feeder. Heated air at about 80°C is blown (from the feed end) through the dryer in the same direction as the paddy moves and exhausted through the exhaust pipe. Heated air acts here mainly as a carrier of moisture from the dryer. While traveling from the feed end to the discharge end of the dryer the parboiled paddy comes in contact with the steam heated pipes for a very short time in each rotation and is gradually dried to about 16 per cent moisture content in a single pass. Therefore, drying is accomplished mainly by the conduction of heat from the steam pipe to the grain. The traveling time of the grain in the dryer is adjusted to 30 to 45 min by adjusting inclination and rpm of the dryer. The hot paddy discharged from the dryer is then aerated by passing it through a cup and cone type cooler.

Advantages

1. Fast rate of drying
2. Uniform drying of all grains.
3. Milling quality of parboiled paddy is high if it is dried in two passes under optimum drying conditions.

Disadvantages

1. Complicated design
2. Needs careful attention
3. Higher capital investment
4. Higher power requirement
5. Operating cost may be high due to higher consumption of electricity and steam.
6. The dryer being horizontal larger floor space is required.
7. Generally only 30 per cent of the dryer volume is utilized.
8. It cannot be used for all types of freshly harvested grains.
The paddy seed contains a rough outer covering, called husk. The husk accounts for about one-fifth to one-fourth the weight of the paddy. The inner kernel called brown rice or dehusked rice, again contains some soft outer layers, jointly called bran. It accounts for some 8-10% of the brown rice weight, including the small germ (1-2% by weight) located in one corner.

Rice milling is the process of removing the husk and a part of the bran from paddy in order to produce edible rice.

Cleaning

Paddy after harvesting and threshing contains some ‘foreign matter’ depending upon harvesting, threshing and handling methods. The foreign matter may be other crop seeds, straw, chaff, sand, stones, dust, pieces of mud and iron particles. Paddy received in the mill must be first cleaned to remove these foreign matters before it can be properly stored. Otherwise they may cause deterioration of the paddy during storage or may damage or obstruct the conveying and milling machinery. Cleaning also helps to reduce storage space. The first cleaning operation of paddy after threshing is called ‘scalping’.
Drying

Intake paddy also generally contains more moisture than is safe for storage and has to be dried. Freshly harvested paddy normally has a moisture content of 18-25%. This moisture must be brought down by drying to ensure a good storage quality. A moisture content of 14% is considered safe for short periods of storage. For long storage, the grain should be dried to 13% moisture or less.

In the drying process, heat supplied by hot air or by the sun evaporates the moisture from the grain, while the moving air carries away the evaporated moisture.

Cracking of Paddy during Drying and How to Prevent it

Drying may cause cracks in paddy and may later lead to breakage of rice during milling. Therefore the drying process must be so adjusted that cracks do not develop in the grains. When paddy is dried, moisture evaporates from grain surface only. Moisture in the interior of the grain moves by diffusion to the surface, and only then it can be evaporated. Diffusion is a slower process compared to evaporation. Therefore during fast drying with hot air or in sun the rate of loss of moisture from the grain surface is greater than the rate of diffusion of moisture from the interior to the surface. The surface, therefore, gets over dried in relation to the center which remains moist. In other words, whenever paddy is rapidly dried, a moisture difference (or moisture gradient) develops between the grain center and the surface. This gradient of moisture causes stress to the paddy grain. If the stress becomes too much due to a steep moisture gradient, the grain cracks. This is the principle of grain cracking during drying.
How are we then to prevent the cracks? Clearly, we have to avoid moisture gradient in grain. One way would be to dry slowly. Then evaporation will be slowed to balance diffusion of moisture and there will be no gradient. But paddy is handled in tones, not in kilograms. Therefore, paddy must be dried fast, not slowly in shade. The only alternative is to stop drying before the moisture gradient becomes excessive. That means, the drying should not be continuous but should be in stages, with rest periods between the drying stages. These rest periods are called ‘tempering’. During tempering, evaporation of moisture from the paddy surface stops, but diffusion of moisture from inside continues. So moisture gets equalized throughout the grain after some time and the moisture gradient is thus removed.

Hence, the grain can now be again dried without danger of cracking. This is the principle of fast drying of paddy without its cracking.

Methods of Drying

**Sun drying:** The most common method of drying is sun drying. The paddy is spread over paved yards in 3-5cm thick layers. It is occasionally turned over to prevent the top layers from over drying and to permit the bottom layers to receive heat and air movement. Sun drying is best done in dry weather with low humidity. Tempering of paddy by heaping between stages of drying and frequent turning over during drying can make sun drying quite effective. Two stages of drying with one tempering are generally satisfactory, for sun drying is not as fast as mechanical drying.

**Mechanical drying:** The alternative to sun drying is mechanical drying. Here paddy is held in a container and hot air is blown through the paddy mass. The dryer may be either batch type or continuous flow type.
**Batch dryers:** a batch dryer can be used when the amount of paddy to be dried is small. It consists of a bin which holds 1-2 tonnes of paddy. The floor of the bin is perforated. Paddy is spread 0.6 – 1.2 meters deep over the perforated floor and heated air is blown through the paddy from below. Air that has passed through the paddy is discharged as cooler, more humid air. After the drying is complete, the paddy is removed and the dryer is ready for another batch.

![Batch Dryer Diagram](image)

**Continuous-flow dryers:** When large volumes of paddy are to be dried quickly, this is the type used. The continuous-flow dryers are of two kinds: nonmixing and mixing types.

In the nonmixing type, paddy flows down between two parallel screens 15-25 cm apart. Hot air is blown through the screen as the paddy moves from the top of the dryer to the bottom. The dryer is usually operated such that the paddy stays for 15-30 minutes in the dryer, i.e, the paddy takes 15-30 minutes to move from top to the bottom of the dryer. Because the grain flows straight down the column, the grains do not get intermixed during drying. Hence there is chance of over drying on the side in which hot air enters and under drying on the side in which the air goes out. However mixing occurs when the paddy is discharged and conveyed from the dryer.

Mixing type columnar dryers are again of two designs. Baffle-type mixing dryer is similar in design to the non mixing dryer above except that there is arrangement of alternate baffles. The baffles cause the paddy to mix as it flows down.

![Continuous-Flow Dryers Diagram](image)

Louisiana State University (LSU) type dryer is another mixing type dryer. It consists of a vertical, rectangular box with rows of air channels shaped like inverted ‘V’s.
One end of the ‘V’s is closed, the other open. The rows alternately open on one side for hot air to enter and then on the next for the air to go out. The rows of ‘V’s are also staggered so that there is good mixing of paddy. Chaff and other light materials are blown out with the exhaust air. LSU dryers are most commonly used in India.

The rate of flow through the dryer is controlled by feed rolls located at the bottom of the dryer. The rolls permit changing the time for which paddy stays in the dryer, hence the rate of drying, as desired.

To avoid the cracking of grains, the intermittent system of drying is to be used. If the intake paddy has a moisture content of not more than 18-20%, drying may be accomplished in two drying stages (or passes) with one tempering in between. If the moisture content is over 20%, three or even four passes of drying with rest in between each successive two passes are necessary. An air temperature of 60-70°C is most commonly used for drying raw paddy.

**Lecture-11**

**Milling of Rice**

Unlike other food grains, rice is mostly consumed as cooked whole grain. Milling technology is therefore geared to obtain maximum outturn of milled rice and to reduce breakage to the minimum.

Rice milling systems range from the home-scale to the large, complex modern rice-processing installations. They include hand pounding equipments, single hullers, battery of hullers, emery sheller-cum-huller mills, emery sheller-cum-cone polisher mills and the modern rubber-roller rice mills.

The single huller mills are by and large located in villages or in localities where paddy is custom milled for producers. Their capacity ranges from 250-750 kg per hour and they still handle the bulk of the country’s production. The large capacity rice mills located in urban or semi-urban areas for commercial milling are of ½ to 4 tonnes per hour capacity and handle the rest of the paddy milled. Some battery hullers are still in operation as large commercial mills, specially for milling parboiled paddy.

**Traditional rice milling machinery**

Traditional rice mills include hand pounding equipments, single huller and battery of hullers, sheller-cum-huller and sheller mills.
Hand Pounding
A variety of implements are used for the purpose of hand pounding, the more common being: (a) mortar and pestle, (b) Dhenki and (c) hand stone (chakki)

Huller mill
The huller mill combines both dehusking and polishing process in one operation. Therefore the by-products, husk and bran are mixed together. The average milled rice recovery in the case of raw rice is low – 65% or less – breakage is high. Besides, it has a larger power requirement per ton of paddy milled than other type of rice mills.

Battery of hullers
These mills consist of a battery of hullers. In addition, sieves for cleaning the paddy, reciprocating sieves for removing broken, aspirator to remove the husk and bran etc are added. The hullers generally work in parallel simply to increase the capacity. As yield from huller is poor with raw paddy, these commercial mills are mostly found in areas where parboiled rice is eaten.

Sheller-cum- huller mill
Here a disc sheller (emery sheller, emery dehusker) is used for dehusking and the huller is used for polishing the dehusked (brown) rice. After cleaning paddy in a sieve, the cleaned paddy is dehusked in a disc sheller and the husk is aspirated. The stock from the sheller is fed to hullers for polishing, often with a screen-type paddy separator in between. The mixture is then sifted and aspirated to remove bran and small broken from head rice. The outturn of rice form this mill is higher by 1-2% over the huller mill for raw paddy.

Sheller-cum-cone polisher mill
The disc Sheller-cum-cone polisher mill consists of a cleaner, disc sheller, aspirator to remove husk, paddy separator, cone polisher and broken rice separator. This mill gives more outturn of rice than hullers by at least 3% (for raw rice). In addition, the head rice yield is higher, for breakage is reduced, bran and husk are separated, the rice is clean and free from paddy and the degree of polishing can be easily controlled.

Small Capacity Rice Mills
Paddy produced in Asian countries is still largely consumed by the farmers themselves. For this reason there is still heavy demand in Asia for a small capacity mill, where small quantities of customer’s rice can be milled.

Engelberg huller:
The Engelberg huller is the most widely used rice mill for this purpose. It is called by different names in different countries, e.g, Kiskisan mill in the Philippines. Hundreds of thousands of hullers are strewn all over the rice countries of Asia.

The huller consists of an ‘iron ribbed cylinder’ mounted on a rotating shaft and fitted in a cylindrical housing. The bottom half of the housing is fitted with a slotted sheet. It combines the dehusking and polishing processes into one operation.
Paddy fed from the hopper is forced to move around the cylinder towards the outlet because of a spiral at the inlet on the revolving cylinder. Friction between the grains and steel parts of the huller causes husk and bran to be scraped off. In the process, the husk and bran are ground into small pieces and are pushed through the perforated screen. Some husk and bran which are discharged with the polished rice are aspirated.

Lecture -12

Modern Rice Milling

Modern mills mean many things to many persons. When one speaks of a modern rice mill complex, one has in mind a fairly big industrial factory. It has a modern, efficient rice mill, a paddy receiving-cleaning-drying section, huge godowns or silos, parboiling-drying system, a huge husk furnace-cum – boiler, ash handling section, bran – handling-processing section, etc.

A modern rice mill as such is a much simpler affair. It is basically a sheller mill, but the sheller is not an emery-disc sheller but a rubber-roll sheller. And it has all the other secondary systems needed for good rice milling. It should be understood that what is called modern mill today is nothing but a mill which incorporates a rubber-roll sheller along with the full combination of a paddy separator, efficient polisher, grader, etc. It should also be noted that disc sheller mills also usually incorporate all these combinations. In such case, these mills approach a so-called modern mill. The extra yield obtained by processing in modern mills is at least 2% in case of raw paddy and about ½ - 1% in case of parboiled paddy as compared to disc sheller-cum-cone polisher mills. Head rice yields in the modern mills average about 5% more than those in sheller mills and 10-15% more than in huller mills.

Modern Rice Milling Process:

Operations and Equipments

A flow chart of important operations, followed in sequence, for milling of rice in a modern rice mill is shown. The operations are as follows:
Cleaning – Removes foreign matter, such as sand, stones, straw, seeds and pieces of iron from paddy.

Dehusking – Removes husk from the paddy with a minimum of damage to the grain.

Husk separation – Removes the husk from the mixture obtained after dehusking.

Paddy separation – Separates dehusked brown rice from remaining unhusked paddy, the paddy being returned for dehusking.

Polishing – Removes all or part of the bran layer from the brown rice to produce polished rice.

Grading – Separates broken from unbroken rice. The broken are separated into different sizes.

Cleaning

Cleaning is the first step in modern rice milling. It not only enables the production of clean rice but also protects the other milling machinery and increases milling capacity.

Impurities that are lighter than paddy are removed by an aspirator. This prevents spreading of dust inside the building and creates hygienic conditions. Metallic (iron) impurities are removed by the use of a magnet. Impurities larger or smaller in size but heavier than paddy are removed by sieves. Vibrating or rotating sieves or a combination of both are used. Impurities that have the same size as paddy but are heavier than paddy are removed by specific gravity separators, namely destoners.

Intake paddy is often subjected to a preliminary partial cleaning (scalping) prior to storage and prior to the main cleaning in the mill.

Cleaner:

The paddy is fed into this machine through an opening in the top. The suction fan draws air through the film of grain and separates all dust and light impurities, which drop to the cone-shaped bottom of the aspiration housing for automatic discharge. The paddy
falls to a vibrating sieve with large perforations which removes large impurities such as straws, big stones, etc. The paddy and remaining small impurities fall to the bottom vibrating sieve with small perforations which removes small impurities. The overflow from this sieve is again subjected to strong aspiration to remove the last traces of light impurities.

**Destoner:** The destoner consists of a perforated deck mounted at angle and operated by a reciprocating motion. A large amount of air is blown from below through the sieve. When a mixture of paddy and stone is fed at the top of the sieve, the air coming through the sieve stratifies the materials according to their density (or heaviness). The heavier stones remain on the deck and are carried backward to the top end by the reciprocating motion of the deck and discharged. The lighter paddy remains floating and slides down and is discharged from the lower end. The separation can be controlled by adjusting the rate of feed, air flow and sieve tilt.
**Magnetic separator:** Type A is a permanent magnet located in such a way that when unclean paddy moves across it, the iron particles are collected by it. The particles are later cleared by hand. Type B is cleaned automatically. The rotating cylinder is turned by the free-flowing paddy. Under the cylinder, there is a half-round magnet. As the paddy passes over the cylinder, iron particles are held by the cylinder’s magnetic attraction. As the cylinder continues to rotate, when the cylinder is not moving over the magnet, the iron is automatically released and discharged separately.

**Dehusking (Shelling)**

The object of dehusking is to remove the husk from the paddy with a minimum of damage to the bran layer and without breaking the brown rice grain.

**Disc sheller:** It consists of two horizontal iron discs coated with emery. The top disc is fixed to the frame housing, and the bottom disc rotates. The rotating disc can be moved vertically up or down to adjust the clearance between the two discs. The clearance is thus adjusted to the size of the paddy grain.
Paddy is fed into the center of the machine. As it reaches the rotating disc, it moves outward by centrifugal force. During its travel outward, whenever it is up-ended, it is caught between the top (stationary) and bottom (rotating) discs and is dehusked by shear. The clearance between the two discs is critical to avoid excessive breakage.

**Rubber –roll sheller:** The rubber –roll sheller consists of two rubber rollers rotating in opposite directions at different speeds. Both rolls have the same diameter, but one roll moves about 25% faster than the other. The difference in peripheral speeds subjects the paddy grains falling between the rolls to a shearing action that strips off the husk. One roller is fixed in position and the other is adjustable laterally in order to increase or decrease the clearance between the two rolls. Rolls are cooled by blowing air on the roll surface. The shelling (i.e dehusking) rate is generally maintained at about 85%.

For operation, at no time should there be a rubber to rubber contact. Otherwise, there would be excessive heat, excessive wear and tear of the rolls as well as discoloring of the grains. The durability or capacity of the rubber rolls varies with cleanliness of paddy, moisture content, pressure applied to the rolls, heating of rolls, the paddy variety (abrasiveness of the husk, short or long grain) as well as the quality of the rolls. A pair of good quality rolls has an average capacity of about 100 tonnes for raw paddy and 200 tonnes for parboiled paddy.

To obtain more operational life per pair of rubber rolls, they should be frequently interchanged to ensure uniform wear. It is best to interchange rolls every 2-3mm of wear. Uneven wear of roll changes the relative peripheral speed and reduces hulling capacity.

Compared with the disc sheller, the rubber-roll sheller has the advantage of giving negligible breakage.

**Husk separation**

A mixture of dehusked rice (brown rice), remaining unshelled that has been split off the paddy comes out of the sheller. This mixture is subjected to sieving-cum-aspiration to separate broken and husk. Sieving prior to aspiration helps in separating
and recovering the small brokenes formed during shelling, particularly from the disc shellers which would be otherwise carried away along with the husk. Light weight paddy husk is separated from the heavier paddy and rice by aspiration.

Husk separator: The mixture of paddy, brown rice, brokens and husk are fed at the top of a vibrating sieve. The brokens pass through the perforations of the sieve. As the mixture of husk, paddy and brown rice overflows from the sieve, air is blown or sucked through the mixture. Husk is carried away by the air. The paddy and brown rice are collected separately.

Paddy separation

Shelling is never done to the level of 100% to avoid rice breakage. The grains also differ in size, so that the smaller grains remain unshelled. Therefore a paddy separator is used to separate the remaining unhusked paddy from husked brown rice. The separated paddy is returned to the dehusker for dehusking while the brown rice is carried forward to the polisher. The separation is accomplished in the separator by taking advantage of the difference in physical density (heaviness), size and surface smoothness (or roughness) of paddy and brown rice.

Compartment – type separator:

The oscillating table is divided into zig zag channels and is inclined from one side to the other along the zig zag channels. The surface of the table is of smooth steel. The table oscillates cross wise, i.e perpendicular to the direction of the channels. The mixture of paddy and brown rice is fed from the hopper to the center of the channels. The impact of the grains on the sides of each channel causes the unhusked paddy grains to move up the inclined slope toward high side of the table. The dehusked brown rice slides
down the slope to the low side of the table. The slope and stroke of the table are adjusted
to meet the needs of paddy of different size or condition and to ensure complete
separation. Usually there are several decks one above the other.

![Diagram of paddy and brown rice being separated](image1)

**Tray separator:** It consists of several indented trays (i.e., trays having a large number of
depressions) mounted one above the other, all attached to an oscillating frame. The tray
section moves up and forward, making a slight jumping movement.

![Diagram of tray separator](image2)

The mixture falls on each tray at the top corner from the inlet hopper. The
smooth, smaller and heavier brown rice tends to go below and paddy to float up due to
the motion of the tray. Further, the brown rice, being smaller, is caught in the
indentations (depressions) and moves upward along with each jump of the tray. Thus it is
carried to the upper side of the tray and discharged there. The free-flowing paddy slides
downwards and is discharged there. Unseparated paddy and brown rice remaining at the
middle portion are discharged in between and are returned to the hopper for recirculation.
The table inclination is adjustable to meet different grain sizes and conditions.
Operation: For efficient paddy separation, feed rate, speed, stroke and table inclination
should be carefully set. Improper setting would result in brown rice going with return
paddy or return paddy going with brown rice, or both, affecting capacity of the plant and
the yield and quality of milled rice.
**Shelling of return paddy**

Paddy collected from the separator is called return paddy, for it has to be returned to the sheller. The return paddy grains are shorter (if in disc sheller) or thinner (if in rubber-roll sheller) than normal paddy. Hence, it is preferable to collect the return paddy in a top bin and shell it at the end with closer clearance between the discs or rolls. Alternately, the return paddy can be shelled in a separate, small sheller. This will increase the capacity of the dehusker. If return paddy is returned to the original sheller, it will simply go on circulating, thus lowering the capacity.

**Polishing**

The brown rice is next polished to remove bran layers. Some amount of polishing is essential for easy cooking and storage, although excessive polishing reduces the nutritive value of rice.

There are two types of polishers, one of emery and other of metal. The emery polishers (called whiteners) polish the grains by abrasion with emery while the metal polishers (called pearler) polish by friction between the rice grains. The emery polishers are again of two types – vertical (cone polisher) and horizontal.

**Cone polisher:** It consists of a vertical truncated cone, covered with emery, which rotates inside a wire screen. The clearance between the cone and screen can be adjusted by raising or lowering the cone. At regular intervals around the cone, the wire screen is divided into segments by vertical adjustable rubber brakes.

The brown rice enters at the top center and moves outward by centrifugal force to the edge of the cone. As the brown rice moves down between the cone and the screen
around the cone, the abrasive action of the emery peels the bran off the grains. The bran
goes out through the screen and is collected separately. The polished rice is discharged at
the bottom.

**Horizontal abrasive polisher:** the machine consists of an abrasive cylindrical emery
stone attached to a steel shaft rotating in a cylindrical, perforated metallic screen mounted
horizontally. Brown rice enters at one end, and moves round and round the abrasive roll
to the opposite discharge end. The pressure on the grain is controlled by hanging different
weights on the discharge gate. As the grain passes through the space between the roll and
the perforated screen, the bran layers are peeled off from the grain. The bran passes out
through the perforated screen and polished rice is discharged through the outlet. The
abrasive roll is made of carborundum.

**Horizontal friction polisher:** the machine consists of cylindrical steel roller rotating
inside a hexagonal perforated screen. The cylinder has a long slit along its length and a
hollow shaft for passing air. The clearance between the screen and cylinder is adjustable
by opening or closing the screen. The pressure on the rice is further controlled by hanging
weights on the discharge gate. A strong stream of air is blown by a centrifugal blower
through the hollow shaft and long slit of the cylinder. The air helps in separating the bran
and removing the heat generated by the friction between rice and rice.

**Operation:** Stepwise polishing in several polishers gives minimum breakage during
milling, thus increasing total and head rice recovery. Keeping the abrasive roller uniform
and in balance reduces grain breakage. When parboiled rice is milled, the bran tends to
stick to the screens. In this case, the quantity of aspirated air is increased to overcome choking of the screens. The bran coming out of the polisher should be checked often to make sure that it does not contain broken rice, not to speak of head rice, ie, to detect any damage to the polisher screen.

Aspiration of air through the polisher prevents heating, thus reducing the breakage, and keeps dust out of the mill.

**Pneumatic bran separator:** This equipment separates rice germs and brokens from bran and also conveys the bran pneumatically (i.e by air). It consists of a powerful centrifugal fan which aspirates the bran from the polisher and delivers it to a cyclone. A blower and an auxiliary cyclone aspirates the bran from the outlet of the main cyclone. Thus fine bran is separated from coarse materials (germs and brokens).

![Pneumatic bran separator diagram]

**Grading**

After polishing operation, the milled rice contains, in addition to ‘whole grains, broken grains of different sizes as well as some bran and dust. Separation of these materials, termed ‘grading’, must now be done. Bran and dust particles are removed by aspiration. Brokens may be separated either by a ‘plansifter’ or by a ‘Trieur’.

**Plansifter:** It is a single or double-decked sieve which is given a swinging motion produced by an eccentric drive. It consists of two sheets of different perforations (first small and then large) to separate two grades of brokens from the polished rice. The grain moves across the swinging sieve in a continuous spiral path.
A plansifter, being of sieve type, cannot separate all broken grains from head rice. Big brokens remain along with head rice, while small brokens (less than half size) are removed.

Sieves of the grader should be kept free from clogging for maximum removal of brokens.

**Trieur:** This is slightly inclined rotating cylinder containing indentations, like small pockets, all along its inner body. The mixed (head and broken) rice is unloaded into the raised end of the cylinder. As the rice passes along the slowly rotating cylinder, the broken grains sit nicely in pockets and are therefore picked up by the rotating cylinder.

But as the cylinder rotates upward, the sitting broken grains finally fall out at a high point and are caught by a collector trough fixed inside the cylinder and discharged separately. The unbroken grains, being too long, cannot sit in the pockets which are too
small. Hence they move along undisturbed down the cylinder as it rotates. Whole and broken grains are thus separated into two streams. By adjusting the size of the indentations and the position of the trough, broken rice of different sizes can be separated.

Broken grains of half or more size are later combined with whole rice in specific proportions to suit market requirements. As big size broken rice is permitted in market rice in India, Indian mills generally use only plansifters and not trieurs.

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**Lecture-13**

**Factors that affect rice outturn during milling**

Outturn of rice from paddy after milling differs from sample to sample. This difference arises from three overall factors.

**Amount of husk in paddy**

First, rice outturn depends on the husk content of paddy. More the husk, less is the rice and less the husk, more is the rice. On an average the husk content of paddy is in the range 20-22%. But there are varieties which have as high as 26% husk and there are other varieties which have as low as 15% husk. Clearly husk content makes a big difference in rice outturn.

**Degree of milling**

Second, rice outturn depends on the degree of milling. The more brown rice is polished, the less is rice outturn and the less brown rice is polished, more is the outturn. By law in India the degree of milling is fixed at 4-5%. But in practice rice is milled as low as 1-2% (‘Government Polish’) and as high as 8-10%. This practice therefore strongly influences rice outturn.

**Breakage of rice**

Third, and by far of greatest importance, is the breakage of rice during milling. Rice is consumed as cooked grains. Therefore there is a preference for whole grains, and broken rice reduces the value of rice. But more importantly, whenever rice breaks, some fine brokens are also produced. These fine brokens may get lost either during sieving or during aspiration. So breakage reduces not only value but also outturn of rice. Therefore grain breakage is the biggest problem in rice milling.

**Other factors:** Does it then mean that all defective or damaged paddy grains will break during milling? No, that is also not true. Here comes the importance of other factors, namely, (a) mill type, (b) size and shape of the variety and (c) moisture content.

a) Practically no type of mill breaks a sound rice grain, as already mentioned. Some types break more of the damaged grains while some can protect them well. For Ex. most damaged rice grains are well protected by a rubber roll sheller, but less so by a disc sheller and very much less by a centrifugal sheller. Similarly more of the damaged grains are broken in a metal polisher than in an emery polisher. So when the paddy to be milled
contains much damaged grains, different mill types give quite different breakage. That is why rubber roll sheller – emery polisher mills are so much better.

b) Size and shape of the variety also influence breakage. More of the damaged grains break in long and slender varieties than in short and round varieties. So we generally find more breakage in fine than in coarse varieties.

c) Again too much moisture in rice makes it soft. So if paddy contains too much moisture during milling, more of the damaged grains break and outturn becomes low.

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Lecture-14

By-products of Rice Milling

Paddy when milled usually yields, apart from marketable rice (head rice + medium and big brokens), 21-24% husk, 3-7% bran and 0.2-2% small brokens and germ, which are the three important by-products of rice milling.

The economic utilization of the by-products, which constitute nearly 30% by weight of paddy processed, is essential for proper viability of the industry. The potential uses of the by-products are given below.

Husk

One-fourth the weight of paddy consists of husk, which makes up the largest milling by-product of rice. It has a high ash content, about 20%, the major portion of which (over 90%) consists of silica. It is not edible, even to animals. It is voluminous and its transportation out of the mill complex is expensive.

Husk has many possible uses. But at the moment its most practical profitable use is as fuel, particularly in the rice mill. Much of this energy need can be met by burning husk. Husk has a calorific value of about 3000 kcal/kg (nearly one-third of that of mineral oil and half that of coal). At the moment, all rice mills doing parboiling raise steam in a boiler by burning husk. Husk is also used as fuel in the household and in small hotel establishments for ease of transportation and storage for such purposes, briquetting machines are available.

Fully burnt white ash of husk contains 95% silica and can be used for manufacturing sodium silicate, silica gel, insulating bricks, etc. If husk is incompletely burnt, the ash can be used as diluent for manure. The ash is also used to increase the bulk of industrial cleaning compositions.

Other applications of husk are as loose insulating material in buildings and cold storages, in shipping as packing material, etc.

Bran

Rice barn is the most valuable by-product of rice milling industry. It contains 12-15% protein, 14-20% oil if the paddy is raw and 18-25% if parboiled, and is a rich source of B-group vitamins.

Bran can be utilized in various ways. It is being used as feed for animals. However, it is a valuable source of vegetable oil and should best be first solvent-extracted to recover the oil. The extracted bran is used as animal feed. The crude oil extracted is
used for the manufacture of soap and fatty acids. Edible grade oil is produced by refining the crude bran oil having low free fatty acids (not more than 8%).

**Broken rice**

Although 5-50% of the rice grains may break during milling, the medium and large brokens as per usual Indian marketing tradition can be mixed with head rice, unless of course the breakage is excessive. Therefore, it is only the very small brokens that are separated during grading of milled rice.

Under normal milling practice, where the stones are not completely removed, the small stones and mud particles collect mainly along with the small brokens. Such small brokens are difficult to use as food and are often used as poultry feed. But when paddy is rigorously cleaned before milling, brokens can be used in the form of semolina or flour with blackgram in preparation of breakfast foods such as Idli and Dosa. A number of deep-fried products are prepared traditionally using rice flour.

**Rice pollards**

Rice pollard which is a mixture of bran 8.5 % of milled product and rice polishing 0.2 %, is a high energy, high protein food.

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**Lecture- 15**

**Principle of Parboiling of Paddy**

Parboiling is a hydrothermal treatment followed by drying before milling for the production of milled parboiled grain. Parboiling of paddy has been known in the orient for centuries. Nearly 50 per cent of the paddy produced in India at present is parboiled.

The parboiling process finds extensive application in the Eastern and part of Southern India, Eastern Madhya Pradesh and Uttar Pradesh. It is also well known in western Uttar Pradesh, Punjab and Haryana in the form of Sela process of parboiling. The process is also being used in Bangladesh, Pakistan, Burma, Ceylon, Malaysia and Thailand. Parboiling has been practiced in the United States, Italy and British Guiana on a commercial scale since 1940.

**Physio-chemical changes during parboiling**

The endosperm of the grain contains mainly polygonal starch granules. The voids or inter granular spaces are filled with air and moisture. That is why it looks opaque. Moreover, there are fissures and or cracks in the grain, developed during maturity, which can cause breakage of rice during milling. The most important change during parboiling is the gelatinisation of starch and disintegration of protein bodies in the endosperm (S.N.Raghavendra Rao, and B.O.Juliano, 1970). The starch and protein expend and fill the internal air spaces. The fissures and cracks in the endosperm are sealed making the grain translucent and hard as a result of which the breakage of grain during milling is minimized.

The colour of the rice changes to yellow or yellowish brown depending upon the paddy variety, soaking time and temperature (pressure of steam), drying time and temperature and many other post harvest factors.
Parboiled rice takes a longer time to cook to the same degree of softness than raw rice of the same variety. The loss of protein and starch from parboiled rice in the cooking water is low. Water soluble B-vitamins and other water soluble nutrients diffuse into the endosperm during parboiling and hence the loss of nutrients is less in parboiled rice even after polishing. The presence of vitamin E is particularly noted in parboiled rice. Slight dextrinisation and destruction of lipase occurs during parboiling. The heat treatment during parboiling causes destruction of some natural antioxidants and may result in increased rancidity of parboiled rice during storage.

In general, the three major steps in parboiling, i.e., soaking, steaming and drying, have a great influence on the final characteristics and quality of parboiled rice. Soaking of paddy is done at or below the gelatinisation temperature. The lower the temperature the slower is the process of soaking and vice versa.

Soaking time can be reduced by subjecting the paddy to vacuum before soaking and or soaking under pressure in hot water. Steaming helps in the gelatinisation of starch in the paddy. The higher the temperature of steam and longer the steaming time, the harder is the rice and darker the colour. Drying of parboiled paddy may be done in the shade, in the sun, or with hot air. Shade drying takes a longer time but results in excellent milling quality. Rapid drying in the sun or with hot air causes higher breakage during milling. In continuous drying, breakage starts as the moisture content reaches about 18 per cent and increases rapidly with further drying. Hence the recommended practice would be to dry in two passes with a tempering in between at about a moisture content of 20 per cent. Normally, the varieties of paddy which are more brittle are preferred for parboiling. The long and slender varieties which are more fragile compared with short and medium length grains are usually parboiled. Scented and tiny varieties which have good milling quality are generally not parboiled.

Soaking

The process of water absorption is known as soaking, steeping or imbibation. It is a diffusion process. As a result of water absorption the paddy swells. The water moves inside the paddy as long as the water vapour pressure inside the grain is less than that of soak water and stops when equilibrium is reached. Soaking is the result of molecular absorption, capillary absorption and hydration. Initially, during soaking, water penetrates the rice kernel and fills up the intergranular spaces due to capillary absorption. Some of the water molecules are absorbed by starch granules while some will enter into the lattice of starch molecule where they will be held as water of hydration.

The volume of paddy increases due to soaking. But the volume of soaked paddy is always less than the sum of the initial volume of paddy and the volume of water absorbed. The soaking process is always accompanied by release of heat. A considerable amount of kinetic energy is lost as heat when water molecules are absorbed.

Soaking is done to provide the starch with a quantity of water sufficient for gelatinisation. The rate of soaking is also dependent on temperature of soaking.

The rate of soaking is high initially but it decreases with time until bursting of the grain takes place when the soaking rate increases particularly at the temperature of gelatinisation and higher.
The initial high rate of soaking is mainly due to quick absorption of water by the hull the filling of space between hull and rice kernal and the capillary absorption in the shallow pores of the pericarp. The absorption of water by paddy is a diffusion process. At higher temperatures the diffusion coefficient increases because of changes in some of the properties of water, such as, vapour pressure, viscosity, density and surface tension. Hence the soaking rate increases as the temperature increases. Absorption of water takes place in two distinct phases. The first phase of soaking continues till the paddy reaches a moisture content of 24-45 per cent depending upon soaking temperature. At this point the grain bursts and rate of soaking becomes very fast. The moisture at which the second phase of soaking starts may be called the critical moisture content in soaking. Its value depends both on the soaking temperature and variety of paddy.

The soaking characteristics of different varieties of paddy are usually different because of the differences in the gelatinisation temperature. The gelatinisation temperatures are normally within 65-75°C. The water absorption also depends on the superincumbent pressure in the soaking tank. In some modern processes vacuum and hydrostatic pressure are used to reduce soaking time, keeping the temperature within desirable limits. The soaking of paddy is associated with an increase in volume.

**Steaming**

Steam is used to complete the gelatinisation process as it does not remove moisture from the paddy rather it adds moisture by condensation. Moreover it has high heat content. During steaming the spread of the water soluble substances inside the paddy grain which is begun during soaking is continued and increased; the granular texture of endosperm becomes pasty due to gelatinisation; any crack in the cayopsis is sealed; the endosperm becomes compact and translucient; most of the biological processes are completely annihilated and the enzymes are also inactivated. If the starch is not fully gelatinized, there will remain white cores in the endosperm. So steaming should be sufficient to cause complete gelatinisation. If there is a higher degree of gelatinisation, it will be reflected in the hardness of the grain, the deepness of colour, the greater amount of cohesion between the layers of perisperm and between the germ scutellum and the endosperm. The time and temperature of steaming are to be controlled in order to get the desirable characteristics in the final product. Fig shows the effect of steaming temperature on the expanded volume. It shows that big increase in volume occurs between steam temperature of 100-120°C.

**Drying**

The parboiled paddy is required to be dried to a moisture of 14-16 per cent to obtain the desirable milling and storing properties. In India, drying is generally carried out on large paved yards in the rice mills. The paddy is dried to a moisture of about 18-20 per cent and then heaped and tempered for few hours and then again dried for 1-2 hrs to bring down the moisture to 14-16 per cent.

The drying is also carried out in mechanical driers in some mills with hot air. The most important aspect in drying is that the process should be carried in two stages. If the drying is continued in one stage below a moisture of 18 per cent there is considerable amount of breakage. But if it is conditioned at that level and again dried to 14-16 per cent moisture, the breakage is considerably reduced.
Lecture-16 & 17

Effects of parboiling on milling, nutritional and cooking qualities of rice

It has been shown that breakage of rice during milling is mostly due to inherent cracks and fissures per cent in the kernel. Parboiling seals the cracks and hardens the grain. The breakage also depends on the milling conditions and the type of milling machinery used. Rice varieties with short grains are usually more resistant to breakage compared to the long slender varieties. The head yield of rice is considerably improved by parboiling particularly for the varieties having very poor milling quality.

Parboiled rice takes longer time compared to raw rice for the same degree of polish. Moreover, parboiled rice requires three to four times as much abrasive load as raw rice to attain the same degree of polish. However to achieve an equal degree of surface bran removal, parboiled rice must be subjected to less polishing than raw rice. For example, for 80 per cent bran removal, parboiled rice must be polished to about 4 per cent.

If the degree of polish is done to a level required for minimum consumer acceptability (80 per cent of bran colour removal) parboiling increases the total yield by 1 to 1.5 per cent and the yield of marketable rice (containing brokens not larger than one quarter the size of the original rice) by about 3.5 per cent.

The concentration of nutrients in the bran is higher than in endosperm. During parboiling many nutrients are diffused inside the endosperm and hence loss during polishing is minimized. Moreover, the improved methods of parboiling retains more nutrients compared to the traditional one. As much as 70 per cent vitamin B is retained in the parboiled rice produced by improved method, whereas the traditional parboiled rice retains only 30 per cent.

The cooking quality of rice is expressed in terms of time of cooking, swelling capacity, expansion ratio, colour, solids in gruel and pastiness.

Raw rice takes about 15-20 min to become fully cooked in boiling water, whereas parboiled rice requires about 30-40 min for a comparable degree of softness. Raw rice cooked beyond 20 min becomes pasty.

Swelling capacity is expressed as the ratio of the final to the initial volume or weight of rice. The water absorption capacity, as expressed by the swelling ratio is significantly lower for parboiled rice than for raw rice cooked for the same period. But if raw rice and parboiled rice are cooked to an equivalent degree of softness, then parboiled rice can absorb more water without losing its shape.

Expansion ratio is the ratio of the dimensions of cooked and uncooked rice both along the length and breadth. At the equivalent degree of softness parboiled rice expands more along the breadth than raw rice, whereas the expansion along the length is not significantly different.

The loss of solids into the gruel is greater in raw rice than in parboiled rice. Discolouration of rice during parboiling is mainly due to non-enzymatic Maillard type browning, that can be inhibited by bisulphate. The husk pigment may also contribute colour by diffusion into the endosperm.
Advantages

1) The process imparts to the grain a hard texture and a smooth surface finish, as a result the brokens in the milled rice is minimized. While 90 per cent of the parboiled grains may remain unbroken the brokens in raw rice could be as high as 50 per cent. The reduction in broken rice results in an increase of 3-5 per cent in the total yield of rice.

2) Insects find it more difficult to bite and eat their way through the hard and smooth surface of parboiled rice.

3) The loss of solids in the gruel during cooking is also less in parboiled than in raw rice.

4) Milled parboiled rice contains more of B-vitamins than milled raw rice.

5) Loss of B-vitamins is less in parboiled rice, during washing and cooking, compared to that in raw rice.

6) The cooking quality is different from that of raw rice. Parboiled rice is non-sticky and non-glutinous.

7) The parboiled paddy on milling produces a bran higher in oil content (about 25-30 per cent oil) compared to raw rice bran (about 10-20 per cent oil).

8) Parboiled rice bran is relatively stabilized compared to raw rice.

Disadvantages

1) It develops a relatively darker colour compared to raw rice.

2) The traditional parboiling process produces an undesirable smell.

3) Parboiled rice takes more time to cook to the same degree of softness than raw rice.

4) Because of long soaking in traditional process, mycotoxins may develop in parboiled rice and cause health hazard.

5) Heat treatment during parboiling destroys some natural antioxidants and hence parboiled rice develops more rancidity than raw rice during storage.

6) Shelled parboiled rice requires more power for polishing.

7) Parboiled paddy may choke the polisher because of the higher oil content of the bran.

8) Parboiling process requires an additional investment of capital.

However, in spite of these disadvantages, the higher outturn of rice (about 1-2 per cent) and higher return from high oil content bran ensures lower price to the consumer and higher return to the miller.
Lecture-18
Methods of Parboiling of Paddy

Rice parboiling process consists of five major steps-soaking, steaming, drying, conditioning and cooling. During soaking the water should penetrate the center of the grain. The water content of paddy after soaking increases to about 50-55 per cent on dry basis. During the steaming process the rice is gelatinized. Finally the paddy is dried to a desirable moisture content so that it toughens enough and does not break easily during milling.

A few Traditional Methods of the traditional premilling treatments to improve the milling, nutritional, cooking and keeping qualities are:

**Atapa**
This treatment originated in Bengal. The paddy is soaked in water at room temperature for 24 hours and then dried in the sun (hence the name atapa or sun-dried). The dried paddy is then milled by traditional methods. The relative breakage of rice is more in this process.

**Balam**
in Bengal. It is slightly better than atapa. Here the paddy is sprinkled with water, which inflates the grain. When the paddy is dried in the sun and milled, the hull is easier to remove.

**Josh**
This treatment was developed in Larkhana; Pakistan. Large earthen pots filled with paddy and water are placed on 15cm layer of hull which is used as fuel. The pots remain on the fire overnight. The next day the water is drained and the paddy is placed on shallow iron pans and heated over fire for one hour. The paddy is then dried in sun.

**Sela**
This treatment was originated in Saharanpur, India. Paddy is soaked in water at room temperature for 20 hours, and then boiled for few minutes. It is finally dried in sun. In this method, rice from over-soaked paddy becomes coarse in appearance, and rice from dried paddy shows poor milling quality.

**Siddha**
The treatment originated in Bengal. Paddy is soaked in water at room temperature for 20 hours, and then boiled for few minutes. It is finally dried in the sun. In this method, rice from over-soaked paddy becomes coarse in appearance, and rice from over-dried paddy shows poor milling quality.
Lecture -19

Parboiling

Parboiling is the latest premilling treatment which improves the quality of rice. The traditional parboiling process in India is carried out in different ways. The principal methods are single boiling and double-boiling process.

The double boiling method (Dobhapa): This involves double steaming in its sequence of operations. The vertical steaming kettles generally two in number, are made of mild steel plates. The size of each kettle is generally 700-900 mm in diameter and 1.2-2 metres in height with about 600 mm deep conical bottom having a 300 mm diameter flanged outlet, fitted with a sliding valve. The flat top cover is fitted with a 300 mm diameter central opening for feeding the raw paddy. The kettles are provided with steam pipe extending vertically through the centre about half way down through the top cover. When the direct stream from the boiler at 6 to 7kg/cm² is used, a 20 to 25 mm diameter steam pipe is supplied.

The soaking is done in large masonry water tanks constructed on the ground floor. These are generally two in number working each in line with a steaming kettle. Each tank usually of 23 metres in depth holds 20 to 35 tonnes of paddy. The water level in the tank is maintained such as to cover the paddy completely during the soaking period.

The process involves filling the dry paddy in the steaming kettle and opening the steam valve. During steaming the top opening of the kettle is covered with gunny bag. Depending on the size of the batch the steam starts blowing out through the bag on the top in three to eight minutes. Steam is turned off and the paddy is discharged from the bottom and then quickly dumped into the water in the soaking tank. The temperature in the tank rises, as more and more paddy is dumped. Finally at the end the temperature of soak water is around 70 to 80°C. But because of large exposed surface, the temperature of soak water drops to 50-60°C within two hours. The paddy is allowed to soak for 24 to 72 hours after which the water is drained off. The colour of the soak water turns brown. In most cases signs of fermentation have been observed within 18 hours. These result in a bad odour and brown colour in the milled rice.

The soaked paddy is then lifted back into the steaming kettles for the second steaming or actual parboiling operation. The procedure followed is the same as is done in case of the first steaming. The parboiled paddy is discharged from the kettles and allowed to dry in the drying yard or in a mechanical drier.

The single boiling method: The paddy is soaked in cold water in the cement tanks for a few days and then steamed in the usual manner. The soaking time is generally more in the case of the single boiling process.

In both these methods, during prolonged soaking of the paddy, the rice prepared out of it produces a bad odour, as a result of fermentation during soaking.
These difficulties are eliminated by the improved methods of parboiling developed in India at the Central Food Technological Research Institute, Mysore, Jadavpur University, Calcutta and in certain other parts of the world.

In the modern methods of parboiling, the long steeping and steaming cycle using low temperatures is replaced by those with short cycles using high temperatures and pressures and the process is carried out either in a batch plant or a semi-continuous or continuous plant.

The treatment will depend on the variety and quality of paddy and the characteristics of the final product desired. The choice of any parboiling technique will also depend on the initial investment, running costs, local conditions and amount of automation desired.

**Improved Parboiling Method of CFTRI, Mysore, India (Batch)**

The system developed by CFTRI (Central Food Technological Research Institute) was primarily aimed at improving the yield and quality of rice with a lower capital investment. The soaking and steaming is done in the same mild steel cylindrical tank. Steam enters through the perforated pipe at the center and there are more perforated pipes arranged radially at the bottom of the tank. The base of the tank is cone-shaped and is closed at the bottom by a water tight hatch. At the side of the hatch there is a valve for draining of the steeping water.

During parboiling the tank is filled with water heated by steam injection to 85°C. The paddy is then poured inside the tank. The temperature of water drops to 70-75°C. After two to three and a half hours steeping, the water is drained off. Pressurized steam is then passed through the perforated pipes until the husks just begin to crack open. After steaming the hot paddy is unloaded through the bottom hatch and then spread over the drying floor.

**Schule process** (Federal Republic of Germany) (Batch)

The process was developed by the well-known German firm, a rice machinery manufacturer. In this process the steam is used only to heat the water. The paddy is put into a pressure tank and is first soaked 120-160 minutes in medium temperature water kept in circulation. When the paddy has reached the temperature of soaking water the water supply is turned off and hydrostatic pressure of 4 to 6 kg/cm² is applied introducing compressed air in the tanks. The second heating or cooking period is started by releasing pressure and readmitting water at a very high temperature to ensure that the starch gelatinizes completely. The water is then drained off and the paddy is dried in a predrier and then in a column drier. The paddy is finally dried to a moisture content of 13 per cent in another column drier after proper tempering.

**Crystal Rice Process** (Italy) (Batch)

In this process the paddy is first soaked in cold water to remove impurities and lighter grains. Steeping is done in a stationary autoclave where vacuum is applied first and water is injected and then high hydrostatic pressure is maintained at controlled temperature. Steaming and drying are done in a rotary autoclave which is also fitted with a steam jacket. The drying is done under vacuum.
Lecture -20

Rice Conversion Process (U.K) (Batch)

The process was patented in the United Kingdom. This was also the first parboiling process adopted in the United States and came into use in 1941-42. Steeping is done in an autoclave after the paddy is deaerated by vacuum. This facilitates water absorption. Then pressure is applied to the steeping water. The combination of vacuum and pressure reduces steeping time to less than three hours. Steaming is done in a rotating steam jacketed autoclave with a pressure of about 1 kg/cm$^2$ for about one hour after which a vacuum is applied to free the grain of excess water. Final drying is done in the same autoclave by applying vacuum keeping the paddy hot by contact with steam heated surfaces. The process is completed in a rotary drier utilizing medium temperature air.

Improved Paraboiling Method of Jadavpur University (Semi continuous)

This process is partly continuous. Steeping is done at 70$^0$C within two and a half to three hours in vertical cylindrical batch tanks. Steaming is carried out in the same tank having perforated steam pipes and is continued only for three to five minutes. After steaming the paddy is rapidly cooled in vertical cup and cone type arrangements. The cooling helps to maintain a lighter colour in the finished rice. After cooling the paddy is then dried in a steam tube rotary drier at a temperature of about 90$^0$C. The paddy is then tempered and cooled before milling.

Maek Process (United States) (Semi continuous)

The above process was patented in the United States. The parboiled rice so produced is amber coloured and fully gelatinized. The grains are very hard. The steeping is done at a high temperature for three to six hours in batch tanks. It is then steamed into a vertical cylindrical autoclave, which has a conical base. The drying is done continuously in a steam heated rotary cylindrical drier and then also continuously in a vertical through flow drier.

Rice Grower’s Association of California Parboiling Process (USA) (Semi continuous)

The process involves a continuous pressure steaming unit. The raw rice is soaked in tepid water for several hours in a tank and then in higher temperature water (varying from 40-90$^0$C depending on the variety) for one to ten hours. It is then steamed continuously under pressure for a short period (15 secs to three minutes) at a pressure between one and five kg/cm$^2$. Drying is done initially at high temperature followed by a batch type column dryer. The paddy is tempered before final pass in the column dryer. The main features of this process are the long soaking time and extremely short exposure to steam at high pressure. As a result the product is very pale in colour and gives a good milling yield.

Avorio Process (Italy) (Continuous)

The process was patented in Italy in 1936. The parboiling procedure is completely mechanized and continuous. Steeping is done by mechanically submerging baskets filled with paddy through a tank. The water is kept in continuous circulation and aerated by blowing in air. Steeping time is between 50 and 120 minutes and is adjusted by
controlling the speed at which the baskets pass through the tank. After steeping the paddy is steamed in continuous pressure autoclave containing rotating perforated cylinders. The paddy is loaded and unloaded through special valves which functions alternately. Pressure may be raised upto 1 kg/cm\(^2\). Before drying the steamed paddy is cooled by a stream of cold air in a rotary cylinder, after which it is transferred to a series of vertical column dryer utilizing air at 45-50\(^0\)C. The rice is amber in colour. In fact, the Italian word, avorio means ivory, referring to the colour of the product.

**Lecture-21**

**Fernandes Process** (Suriam) (Continuous)

The process was patented in 1952. The soaking, steaming and drying operations are carried out in three similarly constructed horizontal rotating cylinders, having internal helical conveyors for movement of paddy. At the center of each cylinder, a perforated pipe extends along the length. This tube carries hot water for soaking in the first cylinder, steam for cooking in the second and hot air for drying in the third cylinder.

**International Rice Research Institute process** (Method under study)

A process is under development whereby freshly harvested paddy is dried using high temperature sand (exceeding 200\(^0\)C). The drier extracts moisture as well as gelatinizes part of the starchy endosperm.

**True Continuous Parboiling Process of Jadavpur University, India** (Method under study)

This process is based on a true continuous system of parboiling consisting of a continuous vertical soaker, continuous horizontal steamer, a continuous fluid bed drier, a continuous vertical conditioner and a continuous vertical through flow cooler. The time and temperature of soaking and steaming can be controlled by controlling the star valve at the bottom of soaker and the steam flow at the soak water tank and the speed of the screw conveyor in the steamer. The residence time in dryer, conditioner and cooler can also be adjusted. The dryer is a horizontal fluid bed dryer where positive movement of paddy bed is made by a flight conveyor.

**RPEC Method** (Indian) (Method under study)

This was developed by Rice Process Engineering Centre, Indian Institute of Technology, Kharagpur during 1970-73. The paddy is soaked in water at or a little above the gelatinisation temperature. The parboiling process is completed by the heat and moisture. No steaming is required. The swellin index of the parboiled rice so produced is similar to the one from conventionally produced parboiled rice. Most important advantage would be that the boiler can be eliminated in a rice mill as no steam is required in the process. Hot water can be generated by suitable husk or coal fired furnace.
Lecture-22

**Sodium Chromate Method** (Indian) (Method under study)

This was developed at Tiruvarur in 1972 (V.Subrahmanyan, 1972)

Oxidizing agent like sodium chromate (0.05 per cent solution) is used in soaking the paddy for 40-48 hrs. This controls putrefactive changes for three days as also reduces the loss of dry matter during cold soaking.

**Brine Solution Method** (Indian) (Method under study)

This is a modified CFTRI method. The modifications and developments were done at the R&D laboratory of the Modern Rice Mill at Tiruvarur, India in 1969. In this method a 15 per cent brine solution is circulated for 10-20 minutes through hot paddy that has been soaked at 65°C and has attained a moisture content of 45 per cent (dry basis). The paddy is then steamed at 3-5 kg/cm² for 15-20 minutes. During drying paddy loses moisture to a level of 14-16 per cent. The main advantage of this method is the reduction in drying time.

**Kisan continuous Parboiling Method** (Indian) (Method under study)

This was developed by Kisan Krishi Yantra Udyog in 1972 (M.A.Kuppuswamy, 1972). A hexagonal tank with 12 compartments is used for soaking in sequential order starting with No.1. By the time the 12 th compartment is filled the first one is ready for steaming. The steaming is continuously done in the annular chamber of a vertical cylinder. The steam is injected into the perforated inner chamber.

**Pressure Parboiling Method** (Indian) (Method under study)

This method was also developed in Tiruvarur in 1969 (C.S.Shivanna, 1971). The paddy is soaked for nearly 40 mins. at a temperature of 80-90°C in a vertical closed tank and then steamed under pressure for 18 minutes. The parboiling is completed in 1 to 1.5 hrs. The rice has a pleasing, slightly yellowish, uniform colour. Main advantages are reduction in soaking time and drying time as also an increase in shelling efficiency (nearly 80 per cent of paddy hull splits during steaming) and an increase in milling out-turn because the grains are resistant to breakage. Several plants have already been installed for commercial production.

Lecture-23

**Ageing of Rice:**

Ageing basically represents the biochemical changes that occur during grain storage. If freshly harvested paddy is milled, the rice gives a pasty gruel when cooked. Under appropriate storage conditions, this characteristic is decreased within weeks and the grains do not tend to adhere to one another when cooked. Storage of milled rice decrease the cohesiveness of the grain. Other changes that can be observed are: drier grain surface, larger volume and firmer texture of the cooked grain, although the cooking time is increased.
Since the new rice is pasty in consistency, more gruel loss occurs and hence it comes under bad cooking quality. If the same rice when stored for 6 months, the amylose content increases, sol gel transformation takes place, cell walls become rigid and leaching loss of solids is very less. In addition to that ageing increases the stabilization of bran and also the % of brokens can be reduced.

**Commercial process involved in artificial ageing:**

Paddy (10-12% m.c)
↓
Steaming (10 min)
↓
Holding for about 30-45 min
↓
Drying
↓
Shelling
↓
Milling

**Artificial ageing/Quick curing of rice:**
It is the process in which new rice can be converted into old rice in a short span.

Milled rice
↓
Steaming (live steam for 30 min)
↓
Mild surface gelatinization
↓
Formation of thin film coating
↓
Sold as steamed rice

**Enriched Rice**

Enriched rice is white rice which has been mixed with an assortment of vitamins and nutrients to make it more nutritious. Many companies make enriched rice, and the packaging usually clearly indicates the level of enrichment in the grain, although those levels may vary after cooking, depending on how the rice is cooked. Most grocers carry several styles of enriched rice, from enriched short grain sushi rice to long grain jasmine rice. When rice is processed into white rice, a great deal of the nutritional value is lost. The fiber and nutrient rich outer bran is stripped first, leaving behind the germ and endosperm. In many cases, the nutritious germ is lost as well during the polishing process. As a result, white rice is not terribly nutritious, naturally. Therefore, some producers add vitamins and minerals back in after the rice has been processed, or they include vitamin pellets in their sacks of rice so that their rice will provide more
nutritional value. Especially in developing nations, enriched rice is extremely important. Since rice is a staple food for millions of people around the world, it is important for rice to be highly nutritious. In regions with a high volume of white rice consumption, nutritional deficiencies have been noted. It is hoped that sales of enriched rice will reverse this trend, by supplementing the daily diet with more vitamins and minerals. Even after enrichment, enriched rice is not as nutritious as whole brown rice. In addition, it should not be rinsed, because the nutrient coated rice will lose value if rinsed. Many companies also recommend that enriched rice be cooked in a minimum of water, so that nutrition is not lost during the cooking process. However, enriched rice is certainly better than plain white rice, especially for people who are relying on it as a staple food.

Lecture-24

Rice Fortification

Rice is a major diet staple in developing nations, and vitamin and mineral deficiency is often prevalent in these countries. Under a cooperative agreement with the United States Agency for International Development (USAID), the Academy for Educational Development (AED) collaborated with the Institute of Food Technologists (IFT) to conduct a four-country assessment of rice fortification with a review of production and fortification techniques in China, Coast Rica, The Philippines and the United States.

Researchers studied four fortification methods, including hot extrusion, cold extrusion, coating and dusting of rice. The authors concluded that the cold extrusion and coating method – similar to the process involving pasta production – could be a practical way to introduce fortified rice in developing nations. The study notes that the hot extrusion method produced the best quality product and maintained the most nutrients; however, it was the most expensive of the flour. While dusting is the least expensive method, it is not recommended for developing countries where washing and rinsing rice before cooking is common and it results in nutrients being washed away.

Methods of Rice Fortification

- Hot extrusion passes dough made of rice flour, vitamin/mineral mix, and water through a single or twin screw extruder and cuts it into grain-like structures that resemble rice grains. This process involves relatively high temperatures (70-110°C) obtained by preconditioning and/or heat transfer through steam heated barrel jackets. It results in fully or partially pre-cooked simulated rice-like grains that have similar appearance (sheen and transparency) as regular rice kernels. The teams visited two companies in China and one in the Philippines that used this technology.

- Cold extrusion, a process similar to one used for manufacturing pastas, also produces rice-shaped simulated grains by passing a dough made of rice flour, vitamin/mineral mix and water through a simple pasta press. This technology does not utilize any additional thermal energy input other than the heat generated during the process itself, thus is primarily a low temperature (below 70°C), forming process resulting in grains
that are uncooked, opaque and easier to differentiate from regular rice kernels. One of the firms visited in Costa Rica uses this process.

- Coating combines the vitamin/mineral mix with ingredients such as waxes and gums. The mixture is sprayed to the rice on the surface of grains in several layers to form the rice-premix and then is blended with polished rice. Manufacturers in Costa Rica, the Philippines and the United States use this process.

- Dusting, observed only in the U.S, involves dusting the polished rice grains with the powder form of the vitamin/mineral premix. The vitamin/mineral mix sticks to the grain surface because of electrostatic forces.

**Lecture-25**

**Processed rice products**

**Rice flour:**
This is made from second heads in pulverizing machines. Rice flour of 9-13 per cent moisture content, contains 5-9 per cent of protein, 0.4-1.0 per cent of fat and yields 0.4 to 0.7 per cent ash. It is used in refrigerated biscuit manufacture to prevent sticking, in baby foods as a thickener, and in waffle and pancake mixes as a water absorbent. In India, rice flour is also used in the preparation of vermicelli, papad, sandig (curds) and in a number of other preparations.

**Parched rice products:** About 4-5% of total supplies of rice in India is converted into rice products-parched rice, parched paddy and rice flakes.

**Parched rice:**
Parched rice is prepared by throwing rice into sand heated to a high temperature in an iron or earthen pan. On stirring, rice begins to crackle and swell. Then the contents of the pan are removed and sieved to separate the parched rice from sand. Parboiled rice is preferred in making parched rice. Parched rice is a crisp product with a grayish to brilliant white colour and is sold either salted or unsalted. It is eaten as such or used mixed with buttermilk or milk.

**Puffed rice from paddy:** Popularly known as “murmuralu”. Paddy is soaked in water to increase the moisture content to about 20%. The moist paddy is puffed by subjecting to sudden heat treatment at 250-270°C for 30-40 sec. The husk splits off and the rice is puffed. Puffed rice prepared in the above manner is made into balls with jaggery and used as a snack.

Puffed rice is used in snack foods and breakfast cereals, and is also a popular street food in some parts of the world. It is an ingredient of bhel puri, a popular Indian chaat item. It is also used in temples and gurudwaras as prasad. A traditional puffed rice called muri is made by heating rice in a sand filled oven. Muri is to rice as popcorn is to corn.

**Rice flakes (Beaten rice):** Popularly known as “pohā”. Rice flakes are produced in large quantities, both on a cottage industrial scale and on a commercial scale in India. The
process is as follows: The paddy is soaked in hot water at 70-80°C for about 20 minutes. The water is drained off. The soaked paddy is toasted in a pan at about 250-275°C till a few grains start puffing. The toasted paddy is immediately subjected to flaking by either pounding with a heavy iron pestle or with a heavy iron roller. The husk is pulverized during the flaking process. Rice flake is a precooked product and can be readily reconstituted by soaking in warm water for 20 minutes. It is widely used in India for the preparation of snacks.

**Instant rice flake preparation**

- Milled rice
  - Soaking (upto 30-35% m.c)
  - HTST process (250-300°C, 5min)
    - Puffing
    - Flaking (0.25 mm thick)
    - Cooling

**Indian instant rice flake preparation**

- Paddy
  - Soaking (70°C for 24-36hr, upto 35% m.c)
  - Roasting (sand : paddy=1:1 at 190-210°C, 30-40sec)
    - Shelling
    - Milling
    - Flaking (0.25 mm thick)
    - Drying
    - Cooling

**Rice starch:** Rice starch granules are quite small and are embedded in a protein matrix. To separate them from protein, broken rice is steeped for 24 hours in 5 times its weights of 0.3% caustic soda. The caustic soda treated, granules are washed, dried and ground into flour. The flour is then mixed with about ten times its weight of caustic soda solution. This removes gluten. After 24 hours, the starch that settles down is removed, washed and dried.
Rice starch is used in puddings, ice-creams and custard powder.

**Instant Rice**

Instant rice, also known as minute rice, is rice that has been precooked and dehydrated so that it cooks more rapidly. Regular rice requires approximately 20 minutes to cook while instant rice needs anywhere between five and 10 minutes. Because it has already been cooked, all that is necessary to prepare instant rice is to simply re-hydrate it with hot water.

**Preparation process:**

Instant rice is made by using several methods. The most common method is similar to the home cooking process. The rice is blanched in hot water, steamed, and rinsed. It is then placed in large oven for dehydration until the moisture content reaches approximately twelve percent or less. The basic principle involves increasing moisture of the milled white rice by using steam or water to form cracks or holes in the kernels. The fast cooking properties come from the fact that, when recooked, water can penetrate into the cracked grain much more quickly.

**Advantages:**

The major advantage of instant rice is the rapid cooking time. Some brands can be ready in as little as three minutes but food experts suggest that instant rice should be cooked for at least five minutes for maximum flavour. Currently, several companies, Asian as well as American, have developed brands which only require 90 seconds to cook, much like a cup of instant noodles. But here, not only is the nutritional value compromised but also the flavour and texture. Because of the short cooking time, this type of rice is usually mushy, another advantage is the variety of flavours available. Items such as chicken, carrots, peas, mushrooms, broccoli, etc are added to make the meal more complete. Ready to eat in approximately ten minutes. Companies like Uncle Ben’s, Kraft, and Rice-A-Roni carry different pre-flavoured varieties which are conveniently packaged as well.

**Disadvantages:**

With convenience comes a price: instant rice is more expensive than regular rice. Rice naturally has minerals like phosphorus, magnesium and potassium. Instant rice has fewer of the calories, carbohydrates and protein than regular rice. Due to its processing, it also loses some of the flavour, but companies compensate by adding herbs and exotic spices and aromas to make it more appetizing. They also try to make up for the loss of nutrients by adding their own nutrients such as the B-vitamins as well as iron.
**Canned rice:**

Milled rice (8% degree of polish) ↓
Soaking (upto 30-35% m.c) ↓
Steaming (10-15 min, m.c upto 50-55%) ↓
Draining ↓
pH adjustment (6-6.5) ↓
filling in sulphur resistant cans ↓
evacuation ↓
sterilization (115°C for 60 min)

Defects in canned rice:
1. Discoloration
2. Lumping
3. Off flavor
4. Inconsistency in texture
5. Pastiness
6. Swelling or bulging

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**Lecture-26**

**Types of wheat**

Wheat types may be classified as hard or soft wheat and strong or weak. Hardness and softness are the milling characteristics relating to the way, the endosperm breaks down. In hard wheat, fragmentation of endosperm tends to occur along the lines of cell boundaries. Whereas the endosperm of soft wheat fractures in random way. This phenomena suggests a pattern of area of mechanical strength and weakness in hard wheat. But fairly uniform mechanical weakness in soft wheat. Hardness is related to the degree of adhesion between the starch granules and surrounding protein. Hard wheat yield coarse, gritty flour, free flowing and easily sifted consists of regular shape particles. Soft wheat gives very fine flour, consists of irregular shape fragments of endosperm cells with some flattened particles which becomes entangled and adhere together sift with difficulty and tend to clog the apertures of sieves. The degree of mechanical damage to starch granules produced during milling is greater for hard wheat than for soft wheat. Hardness effects the ease of detachment of endosperm form the bran. In hard wheat, the endosperm cells comes away more cleanly whereas in soft wheat the endosperm cells tend to fragment. Depending upon the degree of hardness, the principle wheats of the world are classified into :-
i). Extra hard ex: durum, some Algerian varieties

ii). Hard varieties- Manitoba, American hard red spring wheat, Australian prime hard

iii). Medium hard – Russian varieties, American Hard seed winter wheat & some European varieties


Strong and weak wheats:
Wheats yielding flour which has the ability to produce the bread of large loaf vol, good crumb texture and good keeping qualities generally has high protein content and these types are called as strong wheats. Whereas the wheat yielding flour from which only a small loaf vol with coarse open crumb texture having low protein content are generally categorized as weak flour / weak wheat. The flour from the weak wheat is ideal for biscuits and cakes.

The main types of wheat are classified according to their baking strength are as follows:

1) Strong wheat Ex: CWRS (Canadian west Red spring wheat) called as Manitoba. American HR’s, Russian spring type and some Australian varieties.

Medium types: American Hard red winter wheat, some European varieties and some Australian varieties.

Weak wheat: American soft red winter wheat, American soft white varieties.

**Wheat quality:** Quality in the general sense means suitability for some particular purpose as applied to wheat. The criteria of quality are:

i). Yield of end product (wheat – for the grower, flour- for the miller, bread or baked goods for the baker)

ii). Ease of processing

iii). Nature of the end product – uniformity, palatability, appearance and chemical composition.

These criteria of quality are dependent upon the variety of wheat grown & the agroclimate conditions.

Quality requirements: Wheat passes through many hands between the field and the table. All those who handle it are interested in the quality of cereal, but in different ways.

i). The grower requires good cropping and high yields. He is not concerned with quality whether it is fit for milling or not.

ii). The miller requires wheat of good milling quality which is fit for storage, capable of yielding the max amount of flour suitable for a particular purpose.

iii). The baker requires flour suitable for making bread biscuits and cakes. He wants his flour to yield maximum quantity of goods which meets rigid specifications.
iv). Consumer requires platability and good appearance in goods he purchases. They should have high nutritive value and be reasonably priced.

For the miller wheat in a good is

i). Is of good appearance, 
The grains are normal in colour and bright, grains should be free from fungal and bacterial diseases.

ii). Undamaged: The grains are not mechanically damaged by the thresher, by insect infestation, by the rodent attach and have not been damaged by over heating during drying.

iii). Clean: The grain should be free from admixture with chaff, straw, stones, weed seeds and other types of varities.

iv). Fit for storage: The moisture content should not exceed 16% for immediate milling and 15% for storage.

Besides these four aspects of under consideration which are dependent mainly upon agril history of wheat wheat before the miller received is, the miller also wants the wheat to be of good milling quality i.e, to perform well on the mill, to give an adequate yield of flour, to process easily and to yield a product of satisfactory quality. The quality of wheat on the mill is measured by the yield and purity of the flour obtained from it.

**Grading:** There is no official grading system for the wheat. Generally wheat is described as “millable’ or ‘non millable’.

Marketing guide specifies the following requirements for milling the wheat.

i). It should be free from objectionable small , pest infestation, discoloured grains and other injurious metals.

ii). It should not be over heated during drying or storage

iii). Moisture content should not exceed 15% or 16%

iv). Content of admixture should not exceed 2%

v). Pesticide residues should be with in limits prescribed by European countries legislation.

In addition marketing guide classified wheat varieties as

1. favoured from bread making (hard varieties)
2. others-favoured for biscuit and other purposes (soft varities)

The marketing guide recommends a minimum protein content of 10.5 – 11% for bread making with a falling no index of 250 or more is acceptable.

For biscuit making the marketing guide specifies a soft milling wheat with a low water absorption capacity having a protein content of 9-10% with falling no index of 140 or more is acceptable.

The price of wheat for domestic consumption is fixed according to its classes and grade. There are 4 classes for which the minimum requirements are shown as
Minimum quality requirements for wheat

<table>
<thead>
<tr>
<th>Class</th>
<th>Protein</th>
<th>Beleny’s sedimentation value</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>13</td>
<td>38</td>
</tr>
<tr>
<td>II</td>
<td>12</td>
<td>28</td>
</tr>
<tr>
<td>III</td>
<td>11</td>
<td>18</td>
</tr>
<tr>
<td>IV</td>
<td>10</td>
<td>13</td>
</tr>
</tbody>
</table>

With in each class the wheat is graded into one of the 3 grades.

Quality requirements for wheat grades

<table>
<thead>
<tr>
<th>Grade</th>
<th>Min limits</th>
<th>Max limits</th>
<th>Total impurities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heto lt wt.</td>
<td>Falling value</td>
<td>M.C (%)</td>
</tr>
<tr>
<td>1</td>
<td>76</td>
<td>200</td>
<td>15.5</td>
</tr>
<tr>
<td>2</td>
<td>75</td>
<td>150</td>
<td>16.0</td>
</tr>
</tbody>
</table>

Grains which does not confirm to these requirements are termed as “worse grade/ outside grade’.

Lecture-27

Milling of Wheat

Wheat is consumed mostly in the form of flour obtained by milling the grain while a small quantity is converted into breakfast foods such as wheat flakes and puffed wheat. Indian wheats are hard and the moisture content is usually 8-10%.

Table: Percentage composition of nutrients in different parts of wheat kernel

<table>
<thead>
<tr>
<th>Nutrients</th>
<th>Endosperm</th>
<th>Bran</th>
<th>Germ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein</td>
<td>70-75</td>
<td>19</td>
<td>8</td>
</tr>
<tr>
<td>Thiamine</td>
<td>3</td>
<td>33</td>
<td>64</td>
</tr>
<tr>
<td>Riboflavin</td>
<td>32</td>
<td>42</td>
<td>26</td>
</tr>
<tr>
<td>Niacin</td>
<td>12</td>
<td>86</td>
<td>2</td>
</tr>
<tr>
<td>Pyridoxine</td>
<td>6</td>
<td>73</td>
<td>21</td>
</tr>
<tr>
<td>Pantothenic acid</td>
<td>43</td>
<td>50</td>
<td>7</td>
</tr>
</tbody>
</table>

Various steps are involved in making the flour. Figure 2-c gives the different steps. The traditional procedure for milling wheat in India has been stone grinding to obtain whole wheat flour. In modern milling the wheat is subjected to cleaning to remove various types of impurities together with damaged kernels.

- Vibrating screen: This removes bits of straw and other coarse materials and second screen removes foreign materials like seeds.
- Aspirator: It lifts off lighter impurities in the wheat. The stream of grain is directed across screen while air sucks off the dust and lighter particles.
- Disc separator: After the aspirator it moves into a disc separator consisting of discs revolving on a horizontal axis. The surface of the discs indented to catch individual grains of wheat but reject larger or smaller material.
- Scourer: The wheat then moves into the scourer, a machine in which beaters attached to a central shaft throw the wheat violently against the surrounding drum, buffing each kernel and breaking off the kernel hairs.
- Magnetic separator: The stream of wheat next passes over a magnetic separator that pulls out iron and steel particles contaminated during harvesting.
• Washer stoner: High speed rotators spin the wheat in the water bath. Excess water is thrown out by centrifugal force. Stones drop to the bottom and are removed. Lighter material float off leaving only the clean wheat.

• Tempering: Wheat is tempered, before the start of grinding, the process in which moisture is added. Tempering aids in separation of the bran from the endosperm and helps to provide constant controlled amount of moisture and temperature throughout milling. The percentage of moisture, length of soaking, time and temperature are three important factors in tempering with different requirement in soft, medium and hard wheat. Dampered wheat is held in a bin for 8-24 hours. The outer layers of wheat tend to be brittle and tempering toughens the bran coat to permit more complete separation of endosperm. Within the kernel tempering also mellows or conditions the endosperm so that floury particles break more freely in milling.

• Entoleter: Discs revolving at high speed in the scourer aspirator hurl the wheat against finger like pins. The impact cracks down any unsound kernel which are rejected.

• Grinding bin: The "first break" rolls of a mill and are corrugated rather than smooth, break into coarse particles.

• Sifter: The broken particles of wheat and bran go into a box like sifter where they are shaken through a series of cloth or screens to separate larger from the smaller particles. Larger particles are shaken off from the top by leaving the final flour to shift towards the bottom.

• Purifier: The top fractions and particles of endosperm graded by size are carried to separate purifiers. In a purifier a controlled flow of air lifts off bran particles while cloth or screen separate and grade coarse fractions by size and qualities.

• The down purifier: Four or five additional break rolls with successively final corrugations and each followed by a sifter are usually used to rework the coarse stock from the sifter and reduce the wheat particles granular middlings as free from bran as possible. Germ particles being somewhat plastic will be flattened by a later passage through the smooth reduction rolls and tend to be easily separated.

The process is repeated over and over again. Sifters, purifiers reducing rolls until the maximum amount of flour is separated consisting of at least 72% of wheat.
Lecture-28

Milling of Corn

Corn milling

Introduction
Corn is one of the world's most versatile seed crops. Its botanical name is Zea mays. Corn is used as food and feed. Corn can be processed into various food and feed ingredients, industrial products and alcoholic beverages. But the modern corn milling technology developed for the above is mostly confined to some of the developed countries only. However, modern corn milling technology is to be suitably adopted for producing the types of products required for other countries. At present, there are two modern methods of milling of corns, dry milling and wet milling. Besides germ for corn oil extraction and husk and deoiled germ, etc., for feed, grits (mainly used for the breakfast cereals) are the main products of corn dry milling whereas pure starch, germ and feed are the major products of wet milling.

Corn Dry milling

Corn dry milling system can be divided into two groups: the traditional non-degerming system and modern degerming system. In the non-degerming system, the whole corn is ground into meal of high fibre as well as high protein contents by a stone grinder without removing germ. After grinding certain amount of germ and hull can be removed from the meal by sifting.

In the degerming system the corn is moistened with a little amount of water and tempered for moisture equilibration. After degerming the stock is dried, milled and classified into different products. The purpose of all dry degerming corn milling methods is to remove hull, germ and tip cap from the corn kernel as far as practicable and primarily produce corn grits with some meals and flours. The germ is then used for oil extraction and deoiled germ, hull, etc., are used as feed which is known as hominy feed. The yield of endosperm products and hominy feed are about 70 per cent and 30 per cent respectively.

Tempering-Degerming (T.D.) Method of Dry Milling:

The major objectives of this method are: (a) to remove essentially all germ and hull so that endosperm contains as low fat and fibre as possible, b) to recover a maximum amount of the endosperm as large clean grits without any dark speck, and c) to recover a maximum amount of germ as large and pure particles.
Description of the T.D system

The basic operations / processes involved in the T.D method are as follows:
1) Cleaning of the corn
2) Conditioning of the corn by addition of control amount of moisture either at ordinary temperature or at an elevated temperature to toughen the germ and husk and facilitate their removal from the endosperm.
3) Releasing hull, germ, and tip cap from the endosperm in a degermer.
4) Drying and cooling the degermer products obtained from the degermer.
5) Fractionating degermer stock by multistep milling through a series of machines namely roller mills, sifters, aspirators, gravity table separators, and purifiers to separate and recover the various products.
6) Further drying of the products is done as and when necessary.
7) Blending and packaging of products.

Cleaning of corn

Thorough cleaning of corn is essential for the subsequent milling operations. Pieces of iron, etc., are removed by magnetic separators. Dry cleaners consisting of sieves and aspirators and sometimes a wet cleaner consisting of a washing destoning unit and a mechanical type dewatering unit, known as whizzer, are used for cleaning of corn.

Hydrothermal treatment / conditioning

Predetermined amount of moisture is added to the corn in the form of cold or hot water or steam in on6, two or three stages with appropriate tempering times after each stage. The tempering times (rest periods) vary according to the hydration methods. So also tempering temperatures vary from room temperature to about 50°C accordingly.

The optimum moisture content for degerming in the Beall Degermer is 21-25 per cent. Either cold or hot water is used for the addition of moisture. A little heat in the form of open steam is added as and when necessary.

Degerming

The purpose of degerming is to remove hull, tip cap, and germ as far as practicable and leave the endosperm into large grits. However, the products from degermer consists of a mixture of kernel components, freed from each other to varying degrees, with the endosperm particles varying in sizes from grits to flour.

The Beall Degermer consists of a rotating cast iron conical roller mounted on a horizontal shaft in a conical cage.

Part of the cage is fitted with perforated screens and the remainder with plates having conical projections on its inner surface. The rotating cone has similar projections over most of its surface. The feed end of the cone has spiral corrugations to move the corn forward whereas the large end has corrugations in an opposite direction to retard the flow. The product leaves the unit in two streams.

The major portions of the released germ, husk and fines as well as some of the grits are discharged through the perforated screens. Tail stock containing large amount of grits,
escapes through an opening fitted with the large end of the cone. A hinged gate with an adjustable weight adjusts pressure inside the chamber and controls the flow of the stock.

Drying and cooling of degermer stock
The degermer products are to be dried to 15 to 18 per cent moisture content for proper grinding and sifting.
Generally rotary steam tube dryers are used for drying the product. Rotary Louver type dryer can also be employed. The stock is heated to about 50°C.
Counter flow or cross-flow rotary, vertical gravity or fluidized bed types of cooler can be used for cooling the dried products.

Rolling and Grading
Recovery of various primary products is the next step. Further release of germ and husk from the endosperm products occurs during their gradual size reduction roller mills. The germ, husk and endosperm fragments are then separated by means of sifter, aspirators, specific gravity table separators or purifiers.
Sifting is an important operation and is variously referred to as scalping, grading, classifying, or bolting depending upon the means used and purpose. Sifting is actually a size separation operation on sieves. Scalping is the coarse separation made on the product leaving a roller mill or degermer. Grading or classifying is the separation of a single stock (usually endosperm particles) into two or more groups according to particle size. Bolting is the removal of hull fragments from a corn meal or flour.

Corn Wet Milling
It has been discussed earlier that pure starch, pure germ and feed are the basic products of corn wet milling. But a few hundreds of byproducts can be produced from these three main products. A list of these byproducts with their uses is given in Table.
The raw corn for wet milling should contain 15-16 per cent moisture and it should be physically sound. Insect and pest infested, cracked and heat damaged corns (treated at temperature around 75°C during drying) are unsuitable for wet milling. The heat damaged corn affects the quality of oil extracted from its germ.
Sufficient amount of moisture is added to the corn during steeping in the wet milling process in order to prepare the corn for subsequent degerming, grinding and separation operations.
The wet milling process consists of the following steps:
(a) Cleaning, (b) soaking, (c) germ separation and recovery, (d) grinding and hull recovery, and (e) separation of starch and gluten.

Cleaning
All impurities such as dust; chaff, cobs, stones; insect-infested grain and broken grain, and other foreign materials are removed from corn by screening and aspirating. The clean grains are conveyed to the storage bins.
Table.: Corn Wet milling products

<table>
<thead>
<tr>
<th>Product</th>
<th>Feed/food uses</th>
<th>Industrial uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germ oil and meal foods</td>
<td>Livestock</td>
<td>Soap, glycerine, leather dressing</td>
</tr>
<tr>
<td>Refined oil</td>
<td>Salad and table oils, cooking oils, margarine</td>
<td>Pharmaceuticals</td>
</tr>
<tr>
<td>Steep water</td>
<td>Yeast food</td>
<td>Phytic acid, inositol</td>
</tr>
<tr>
<td>Gluten and hulls</td>
<td>Livestock and poultry feed</td>
<td></td>
</tr>
<tr>
<td>Starch</td>
<td>Corn starch, chewing gum, bakeries, baking powder, brewing confectionery</td>
<td>Textiles, laundry, paper and paper boxes, explosives, cosmetics, adhesives</td>
</tr>
<tr>
<td>Syrup</td>
<td>Bakery products, canned fruits, ice cream, confectionery, soft drinks, chewing gums, mixed syrups and jellies</td>
<td>Textiles, leather tanning, pharmaceuticals, tobacco</td>
</tr>
<tr>
<td>Sugar</td>
<td>Bakery products, pharmaceuticals, jams and jellies, ice cream, canned foods, confectionery</td>
<td>Rayon, tanning, fermentation, brewing, vinegar, carmel colour, fermentation products, tobacco</td>
</tr>
</tbody>
</table>

Steeping

The major objectives of steeping are 1) to soften the kernel for grinding, 2) to facilitate separation of germ, 3) to facilitate separation of gluten from the starch granules, and 4) to remove solubles, mainly from the germ.

Water impregnated with SO₂ (i.e., acidulated water with H₂SO₄) is used for steeping. It helps in arresting certain fermentation during long steeping process.

The steeping is carried out at about 50°C for a period varying from 28 to 48 hours in different plants. The steeped corn attains a moisture content of about 45 per cent.
The flow diagram of corn wet milling process is shown in Fig.

Shelled corn
↓
Cleaners
↓
Storage bins
↓
Corn washers
↓
Steep tanks
↓
Degerminators
↓
Germ separators
↓
Germ
Steep water concentrate
↓
Drying
↓
Grinding mills
↓
Washing
↓
Germ
Starch washing filters
↓
Feed
↓
Dryers
↓
Starch
↓
Converters
↓
Refining
↓
Dry starches
↓
Dryers
↓
Roasters
↓
Dextrins
↓
corn syrup
↓
drum of spray dryers
↓
sugar crystallisers
↓
Centrifugals
↓
molasses
↓
Dextrose
↓
Corn syrup solids
↓
Drum of spray dryers
↓
Centrifugals
↓
molasses
↓
Dextrose

Flow diagram of Corn wet milling and refining processes
Germ Recovery

The wet and softened corn kernels containing about 45 per cent moisture are conveyed to the degerminating unit. This machine consisting of a metallic stationary plate and a rotating plate with projecting teeth is employed only for tearing the soft kernels apart and freeing the germs without grinding them.

The pulpy mixture containing germs, husk, starch and gluten is passed through hydroclones, where the germ being lighter is separated from other heavier ingredients, by centrifugal force. Only modern starch plants employ hydroclones for germ separation. Otherwise the floatation method of germ separation is still in use in old types of mills.

Milling and Fibre Recovery

After separation of germ and screening of the coarse particles, the mixture contains starch, gluten and hulls.

Mainly horny endosperm and hull are then generally ground by either traditional Burstone mill or modern entoletor impact mills to release the rest of the starch. Material to be ground enters the machine through a spinning rotor and is thrown out with great force against the impactors at the periphery of the rotor and also against a stationary impactor resulting in considerable reduction in particle size. Here only the starch is readily released, with a very little size reduction of hulls.

The milled slurry, containing the ground starch, gluten, and hulls, is passed through a series of hexagonal reels where the coarser hulls and fibres are removed.

Starch- Gluten separation

In the modern process, the slurry containing starch and gluten is concentrated and then the lighter gluten particles are separated from the relatively heavier starch particles by the centrifugal force in high speed centrifuges. The centrifuging of starch is carried out in two stages. In many modern plants, the second stage of centrifugation is performed by a number of hydroclone type of equipments.

The starch obtained from the second stage of separation is filtered and then dried to produce dry starches.

Products of corn milling

Degerminated flour: This represents about 70 per cent extraction. The degerminated flour consists mostly of the endosperm and has low content of B-vitamins. It is used by brewers as a starch medium for the action of barley malt in the preparation of wort for the production of beer.

Germ: Corn-germ contains about 21.0 per cent proteins and 32 per cent fat. Since the germ constitutes about 13 per cent of the grain, it is an important source of proteins and fat. The oil can be extracted by solvent extraction and the residual protein-rich (about 30 per cent protein) corn germ flour can be incorporated in weaning foods.
Lecture-29
Milling of Barley, Oats and Rye

BARLEY
Barley is used to a small extent as a food in the form of pot barley or pearl barley or barley flour. It is used mostly in the preparation of malt. Barley is used to a limited extent as a staple cereal in some parts of North India.

Pot and pearl barley: Both pot and pearl barley are manufactured by gradually removing the hull and aleurone layer of barley kernel by abrasive action. Two types of machines are used. One type consists of a cylindrical millstone which revolves at about 450 rpm. The second type is pearling machine consisting of 6 to 8 abrasive discs (coated with carborundum or emery) which are rapidly revolving. The hull and aleurone layer of barley are removed by rubbing against the millstone or emery disc. The dehusked barley is subjected to pearling. After the third pearling, the bran is almost completely removed along with a part of the aleurone layer. At this stage, the product may be graded and sold as pot barley. When the grain is subjected to 5 to 6 pearling operations, the resulting pearl barley is small, round and white. One hundred kg of barley normally yields about 65 kg of pot barley or 35 kg of pearl barley.

Barley flour: Pot barley or pearl barley is ground to fine flour and sold as barley flour.

OATS
The oat, grain consists of (1) husk, (2) aleurone layer, (3) germ and (4) endosperm. The important oat products of commerce are rolled oats and oat flakes. Oats free from the husk are called groats.

The steps involved in the milling are (1) cleaning, (2) drying or light roasting of oats to a moisture content of 6 per cent and (3) dehulling.

Cleaning: The initial step in oat milling process, as with other grain is cleaning of the grain to remove extraneous matter, such as other cereal grains, weed seeds, chaff, etc', and to separate the light oats.

Drying: The next step is to reduce the moisture content to about 6 per cent so as to facilitate the removal of the husk. The drying is carried out by a light roasting process which also helps to develop a desirable flavour in the groats.

Dehulling: The lightly roasted oats are gradgd and each lot is passed through hullers, similar to those used for hulling paddy. The husk is removed and the groats thus obtained are used for being processed into rolled oats, oat flakes, etc.

Rotted oats

The groats are steamed directly with live steam. This process partially cooks the oats and also inactivates the enzymes, lipase and lipoxidase present. This will help to prevent the development of rancidity and increase the shelf-life of the product. The next
step is the flaking process. This is accomplished by feeding the steamed groats between two large steel rolls. The yield of rolled oats is usually about 40-45 per cent, as about 20 per cent of the hulls and 30-35 per cent of other products such as oat shorts, and oat middling and other cereal grains are removed during cleaning, milling and flaking processes.

**RYE**

Rye is cultivated extensively in Europe and used along with whet flour in bread making. The rye grains are long and slender.

Milling: Rye milling is an important industry in Europe and differs in many respects from normal wheat milling. The rye is cleaned and conditioned. It is passed through successive break rolls and the husk is aspirated. Finally the purified middlings are passed through reduction rolls. Rye flour thus obtained is dark in colour.

Rye bread: Rye bread is not made generally with yeast; instead sour dough is used for fermentating the dough. Sour dough contains lactic_acid bacteria. It is customary to mix wheat flour with rye flour to the extent of 20 to 30 per cent.

The rye breads are baked in the same way as wheat bread.

**Lecture-30**

**Milling of Sorghum, Bajra and Ragi**

**Milling of sorghum:** Sorghum grains are processed by dry milling, wet milling and by fermentation. The products of milling are chiefly starch and feed products. In India however, very few processed products of sorghum are commercially produced. Dry milling is used to obtain products low in fiber, fat and ash, and wet milling to make starch and its derivatives. The residue from wet milling is used as a feed.

The dry milling process starts with the cleaning of grains. The cleaned grain is conditioned, by addition of water, to soften the endosperm and milled by the conventional roller mills, to separate the endosperm, germ and bran from each other. The endosperm is recovered in the form of grits, with the minimum production of flour. Yields of various fractions from the dry milling process are: grit, 76.7; bran, 1.2; germ, 11; and fiber, 10 percent. Bran and germ are further processed, as in the case of maize, by dry milling for the preparation of oils and feeds.

Wet milling of sorghum is carried out by methods similar to that of maize wet milling. However, the milling of sorghum is more difficult than that of maize because of the small size and spherical shape of the sorghum kernel and the dense high protein peripheral endosperm layer. Manufacture of starch is the main purpose of wet milling.

Sorghum is as good as barley for malting purposes. The sorghum malt is used in the preparation of infant foods and malt extracts produced from sorghum are employed in the pharmaceutical industry.

**Millets**

The name millet is applied to numerous small seeded grasses which originated in Asia or Africa. Apart from maize and sorghum, the major millet crops of India are Pearl millet called bajra and finger millet known as ragi. A number of other minor millets are grown and they are: the common millet or proso millet, foxtail millet and kodo millet.
These millets along with maize and sorghum, are considered as coarse grains and constitute the food of the economically weaker sections of the population in India.

Pearl millet (Bajra): Among millets, bajra is the predominant crop in India. About 85% of bajra produced in country is used as food. It constitutes the staple diet of nearly 10% of Indian population. It is consumed after dehusking and cooked in the same way as rice. More commonly it is ground into flour and made into chapattis. It is also made into thin porridge.

Bajra grains, ground or softened by soaking in water, find use to a limited extent as animal feed. The processing of bajra and other millets for industrial purposes has not yet been developed.

Finger millet: The finger millet or ragi is another important millet cultivated in India. Ragi is the principal food grain of the rural population in India, especially in the southern region. It is usually converted into flour and a variety of preparations like mudde, chapatti, dosa, porridge etc are prepared. The grain is also malted and the flour of the malted grain is used as a nourishing food for infants and invalids. The nutritive value of ragi is better than that of rice and other cereals.

Lecture-31

Malting of Cereals

Barley is commonly used for malting in many countries. Other grains such as wheat, sorghum and ragi have also been used to a limited extent in the preparation of malting of cereal grains consists of the following steps:

1. selection of the grain and cleaning,
2. steeping of the grain in water,
3. germination of the steeped grain in trays or drums,
4. controlled slow drying of the germinated grain (kilning) and
5. removal of rootlets by cleaning on wire mesh.

Selection of the grain and cleaning: The grain should be of good quality and free from infestation. The seed selected should have high germination capacity. The gain is cleaned of all impurities and graded to remove undersize grains.

Steeping: The grain is steeped in cold water for 36 hours in warm climate with two or three changes of water. The steeping may have to be for longer periods-(48 to 72 hours) in cold climates.

Germination (couching): The steeped grain is spread on wire mesh, trays of 2-3" thickness which are kept in a stand. The germination is allowed to proceed for 3 days in a warm climate. In colder climate, longer periods may be required for germination (4-6 days). The grains are mixed up once in 24 hours and water is sprinkled over them. The room in which the trays are kept is aerated by blowing moist air at a slow rate. During germination, amylases and proteinases are formed.
**Kilning:** Efficient kilning consists of, drying the germinated grain at a slow rate. During slow drying, the amylases act on starch hydrolyzing it to dextrins and proteases act on proteins hydrolyzing them to proteases and peptones. The drying should be at a low temperature with a view to conserve as much of the enzyme activity as possible. Usually, the temperature is slowly raised to 140°F during the course of 6-10 hours from the time the wet malt is loaded for kilning. During kilning, the water-soluble carbohydrates and nitrogen (peptones and peptides) increase. The characteristic malt flavour is developed. The malt is dried to a moisture content of about 13 per cent.

**Uses of malt**
Malt is used in brewing and in the preparation of malt extract for pharmaceutical purposes and in the preparation of, malted milk powder.

**Brewing:** The steps involved in the preparation of beer from malt are as follows:
1. Mashing of powdered malt with gelatinised wheat flour in water at 37-40°C.
2. Filtration and clarification of the wort (extract)
3. Addition of hops to wort and boiling.
4. Cooling of wort and fermentation of wort by yeast at controlled temperature (46-52°F)
5. Filtration and storage of beer and
6. Pasteurisation, bottling and carbonation

**Malt extract**
The steps involved in the preparation of malt extract are as follows:
1. Mastring of the powdered malt with gelatinized wheat flour,
2. Filtration, (3) concentration and (4) packaging;

**Mashing:** Powdered malt (from malted barley or sorghum or ragi) is suspended in 8 times the weight of water at 35-40°C. Wheat flour is cooked in 8 times its weight of water and cooked to 35-40°C. The mixture is transferred to the mashing tank and is mixed with a suspension of powdered malt in water. Mashing is carried out by raising the temperature of the mixture to 40-50°C for 2 hours and 55-60°C for 1 hour. During this period the amylolytic enzymes of malt act on the starch and convert it into dextrins and maltose and the proteases act on proteins.

**Filtration:** After the mashing is complete, the unreacted material is removed by centrifuging the mixture in a basket centrifuge. The malt extract thus obtained contains about 15 per cent solids.

**Concentration:** The clarified malt liquor obtained above is concentrated, under vacuum in a falling film evaporator to 40-50 per cent total solids. Further concentration to 78-80 per cent total solids is effected in a standard vacuum pan. The malt extract thus obtained is a thick viscous light brown product with a pleasant aroma and taste.

**Packaging:** The malt extract is packed in tins of 25 lbs capacity.
Lecture-32
Breakfast Cereal Foods

Ready-to-serve breakfast cereal foods are manufactured in different countries and have become quite popular. These include (1) flaked breakfast cereals, (2) puffed breakfast cereals, (3) shredded and granular breakfast cereals and (4) puffing by extrusion.

**Flaked breakfast cereals:** The common cereal flakes commercially available are corn flakes, wheat flakes, rice flakes and oat flakes. The general methods of preparation of cereal flakes are as follows: (1) milled whole or broken cereal grains are cooked in steam, (2) cooked cereal is flaked in a flaking roller and dried and (3) the flakes are toasted and packed. During the preparation of the flakes, the nutritive value of the proteins is adversely affected and a part of B-vitamins present is destroyed.

**Puffed breakfast cereals:** The puffed breakfast cereals of commerce include those from wheat, rice, barley, corn etc. The process consists of the following steps: (1) the grain is soaked in hot water till it absorbs about 20 per cent water and (2) the moist grain is introduced into puffing guns and puffed.

**Shredded breakfast cereals:** The most popular representative of this class is shredded wheat. This is made from whole wheat which, is cooked in boiling water for 1 hour. It is partially dried and passed through shredding rolls. The shredded wheat is dried in an oven at 250°F for 30-60 minutes.

**Granular breakfast cereals (grape nuts):** The most widely used cereal granules are grapenuts. It consists of fragments of toasted bread. The process manufacture is as follows: A stiff dough is made of a blend of wheat flour, malted barley flour, salt, bakers yeast and water. The dough is maintained at 80°F for 5 hour. The dough is formed into loaves and paked at 400°F. The baked loaves are fragmented by shredding knives or saws and the pieces are toasted x 250°F for 2 hours. The pieces are broken up into small granules and packed.

**Puffing by extrusion , (Wenger process) :** Puffed breakfast cereal foods in many attractive shapes as well as many kinds of snacks are being manufactured by the Wenger process. The process consists of the following steps: (l) The cereal flour blend is cooked into a stiff dough. The dough is cooked under pressure of 30-40 pounds per square inch and temperature of 300-350°F and extruded through the die. The extruded product is sliced off by revolving blades. The dough pieces expand rapidly as they leave the die. Since, they still contain about 26-27 per cent moisture, they are dried in a hot air drier. The process can be used for preparing weaning foods by adding protein-rich foods, vitamins and minerals to the cereal flour.