Post Harvest Technology of Cereals, Pulses and Oilseeds

Revised Edition

A. Chakraverty

POST HARVEST TECHNOLOGY

OF CEREALS, PULSES AND OILSEEDS

Revised Edition

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Dedicated to

my mother

GRAIN PROCESSING. He is also indebted to Mrs. S. Chakraverty for her kind painstaking assistance in the preparation of the manuscript.

The authors wish to acknowledge the cooperations of the students of Post Harvest Technology Centre, Indian Institute of Technology, Kharagpur in checking some problems.

The authors pay their homage to the pioneers in research and development of post harvest technology of cereals and pulses.

A. CHAKRAVERTY

I.I.T., Kharagpur,
May 1981

D. S. DE

PREFACE TO THE SECOND EDITION

The second edition of this book has been revised and corrected as far as possible A chapter on processing of oil seeds is also incorporated. Though the book was out of print for some time, the book remained equally popular to the teachers, researchers and students. A special word of thanks is due to them.

The author is grateful to Professor A. N. Bose and Professor S. Mukherjee for their contribution on parboiling of paddy and to Professor D. S. De for his encouragement and to Mrs. S. Chakraverty for her painstaking effort to correct the printing mistakes.

August, 1987
IIT, Kharagpur

A. CHAKRAVERTY

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SECTION I

GRAIN DRYING AND DRYERS

CHAPTER 1

Structure, Chemical Composition, Physico-thermal and Aerodynamic Properties of Grains

Grain is a living biological product which germinates and respires also. The respiration process in the grain is externally manifested by the decrease in dry weight, utilisation of oxygen, evolution of carbon dioxide and release of heat. The rate of respiration is dependent upon moisture content and temperature of the grain. The rate of respiration of paddy increases sharply (at 25° C) at 14 to 15 per cent moisture content which is called the critical point. On the other hand the rate of respiration increases with the increase of temperature to 40° C. Above this temperature the viability of the grain as well as the rate of respiration decreases significantly.

Structure

Wheat and rye consist mainly of pericarp, seed coat, aleurone layer, germ and endosperm whereas oats, barley, paddy, pulses and some other crops consist not only of the above five parts but an outer husk cover also. The husk consists of strongly lignified floral integuments. The husk reduces the rate of drying significantly.

The embryo or germ is the principal part of the seed. All tissues of the germ consist of living cells which are very sensitive to heat. The endosperm, which fills the whole inner part of the seed consists of thin-walled cells, filled with protoplasm and starch granules and serves as a kind of receptacle for reserve foodstuff for the developing embryo. The structures of a few important grains are shown in Figs. 1.1 to 1.4.

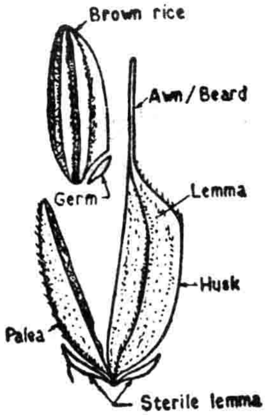

FIG. 1.1. Different Parts of Paddy.

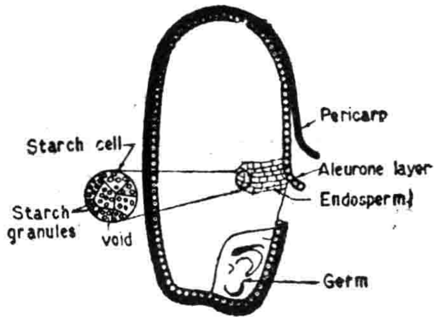

FIG. 1.1a. Structure of Brown Rice Kernel (Longitudinal Section).

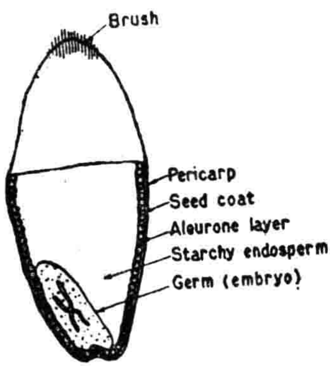

FIG. 1.2. Structure of wheat.

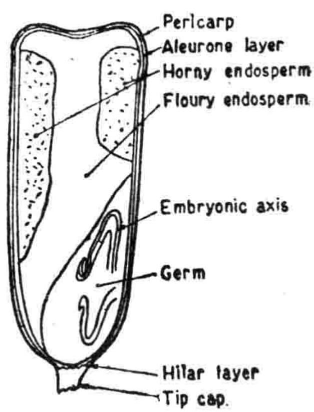

FIG. 1.3. Structure of shelled corn (Longitudinal section).

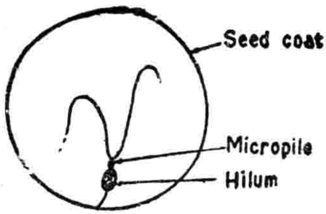

FIG. 1.4. Whole arhar pulses (*Cajanus-Cajan*).

Chemical Composition

The grain is composed of both organic and inorganic substances, such as carbohydrates, proteins, vitamins, fats, ash, water, mineral salts and enzymes. Paddy, corn, wheat, buck wheat seeds are specially rich in carbohydrates whereas legumes are rich in proteins and oil seeds rich in oils.

Generally, pericarp (and floral integuments also) contains cellulose, pentosan and ash, the aleurone layer contains mainly albumin and fat. The endosperm contains the highest amount of carbohydrate in the form of starch, small amount of reserve protein and a very little amount of ash and cellulose whereas the germ contains the highest amount of fat, protein and a small amount of carbohydrate in the form of sugars and a large amount of enzyme. The chemical compositions of different grains are given in Table 7 (Appendix).

Effects of temperature on the quality of grain

Proteins

The proteins present in cereal grains and in flour are hydrophillic colloids. The capacity of flour proteins to swell plays an important role in the preparation of dough. At temperatures above 50° C denaturation and even coagulation of proteins take place. As a result, the water absorbing capacity of the proteins and their capacity for swelling decreases.

Starch

Starch is insoluble in cold water. It swells in hot water. Up to a temperature of 60° C, the quality of starch does not change appreciably. With a further increase in temperature, particularly above 70° C, and especially in the presence of high moisture in the grain, gelatinisation and partial conversion of starch to dextrin take place. In addition, a partial caramelisation of sugars with the formation of caramel may take place which causes deterioration in colour of the product. These effects have been discussed in detail in Section II on Parboiling.

Fats

Fats are insoluble in water. Compared to albumins and starch, fats are more heat resistant. But at temperatures above 70° C, fats may also undergo a partial decomposition resulting in an increase of acid numbers.

In the range of temperatures from 40 to 45° C, the rate of enzymatic activity on fats increases with the increase of moisture and temperature. With a further rise of temperature the enzymatic activity begins to decrease, and at temperatures between 80 and 100° C the enzymes are completely inactivated.

Vitamins

The heat sensitive B-vitamins present in the germ and aleurone layer are destroyed at high temperature.

Physical Properties

The knowledge of important physical properties such as shape, size, volume, surface area, density, porosity, colour, etc., of different grains is necessary for the design of various separating and handling, storing and drying systems. The density and specific gravity values are also used for the calculation of thermal diffusivity and Reynolds number. A few important physical properties have been discussed here.

Sphericity

Sphericity is defined as the ratio of surface area of sphere having same volume as that of the particle to the surface area of the particle. Sphericity is also defined as :

$$\text{sphericity} = \frac{d_i}{d_c}$$

where d_i = diameter of largest inscribed circle and d_c = diameter of smallest circumscribed circle of the particle. The sphericity of different grains vary widely.

Porosity

It is defined as the percentage of volume of inter-grain space to the total volume of grain bulk. The per cent void of different grains in bulk are often needed in drying, air flow, and heat flow studies of grains. Porosity depends on (a) shape, (b) dimensions, and (c) roughness of the grain surface.

Porosity of some crops are tabulated as follows :

Grain	Porosity per cent
Corn	40—45
Wheat	50—55
Paddy	48—50
Oats	65—70

COEFFICIENT OF FRICTION AND ANGLE OF REPOSE

Angle of repose and frictional properties of grains play an important role in selection of design features of hoppers, chutes, dryers, storage bins and other equipment for grain flow.

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 frictional coefficient depends on (a) grain shape, (b) surface characteristics, and (c) moisture content.

Angle of repose

The flowing capacities of different grains are different. It is characterised by the angle of natural slope (angle of repose).

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.

The angle of repose for a few important grains are tabulated as follows :

Grain	Angle of repose (degrees)
Wheat	23—28
Corn	30—40
Millets	20—25
Rye	23—28
Oats	31—44
Barley	28—40
Paddy	30—45

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

The specific heat of a substance is defined as the amount of heat required to raise the temperature of unit mass through 1° C. The specific heat of wet grain may be considered as the sum of specific heat of bone dry grain and of its moisture content. It can be expressed as follows :

$$c=\left(\frac{m}{100}\right) c_w+\left(\frac{100-m}{100}\right)cd_r$$

$$\text{or} \quad c=\left(\frac{m}{100}\right) \quad +\left(\frac{100-m}{100}\right)cd_r \ \frac{\text{kcal}}{\text{kg°C}}$$

where cdr = specific heat of the bone dry grain ; c_w = specific heat of water ; and m = moisture content of the grain, per cent (w.b).

The specific heat of bone dry grain varies from 0.35 to 0.45 kcals/kg° C.

The above linear relationship between C and m exists above m = 8 per cent moisture content only (Gerzhoi, A.P., 1958).

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. The thermal conductivity of the single grain varies from 0.3 to 0.6 $\frac{\text{kcal}}{\text{m. hour}^\circ\text{C}}$ whereas the thermal conductivity of grains in bulk is about 0.10 to 0.15 $\frac{\text{kcal}}{\text{m. hour}^\circ\text{C}}$ which is due to the presence of air space in it. The thermal conductivity of air is 0.02 $\frac{\text{kcal}}{\text{m. hour}^\circ\text{C}}$ only.

Thermal conductivity of the single grain is three to four times greater than that of the grain bulk. The thermal conductivity of the wheat bulk with moisture contents ranging from 10 to 20 per cent (d.b) can be expressed as follows (Gerzhoi, A. P., 1958).

$$K = 0.060 + 0.002\,M \text{ kcal/m. hour }^\circ\text{C}$$

where K = thermal conductivity

M = Moisture content (d.b).

Aerodynamic Properties

For designing air and water conveying and separating systems (i.e., pneumatic or hydrodynamic systems), the knowledge of aerodynamic and hydrodynamic properties of agricultural products is necessary. In this connection the knowledge of terminal velocities of different crops in a fluid is necessary.

The air velocity at which an object remains in a suspended state in a vertical pipe under the action of the air current is called terminal velocity of the object.

Thus in free fall, the object attains a constant terminal velocity, V_t, when the gravitational accelerating force, Fg becomes equal to the resisting upward drag force Fr.

Hence, $Fg = Fr$ when $V = V_t$

$$\text{or} \quad W\left[\frac{\rho_p-\rho_t}{\rho_p}\right] = \frac{1}{2}\; Ca_p\,\rho_t\,V_t^2$$

$$V_t = \left[\frac{2W(\rho_p-\rho_t)}{\rho_p\,\rho_t\,a_p C}\right]^{1/2}$$

V_t = terminal velocity, m/sec

W = weight of the particle, kg

ρ_p, ρ_f = mass density of the particles and fluids, $\frac{kg-sec^2}{m^4}$

a_p = projected area of the particle perpendicular to the direction of motion, m^2

C = overall drag coefficient (dimensionless).

Grains	Terminal velocity, m/sec
Wheat	9 —11.5
Barley	8.5—10.5
Small oats	19.3
Corn	34.9
Soybeans	44.3
Rye	8.5—10.0
Oats	8.0— 9.0

RESISTANCE OF GRAIN BED TO AIR FLOW

In the design of blowers for grain dryers, it is necessary to know the resistance exerted by the grain bed to the air current blown through it. The resistance is dependent upon : (a) the bed thickness, (b) the air velocity, (c) orientation of the grains, and (d) type of grain.

Symbols

a_p Projected area, m^2
c Specific heat, kcal/(kg°C)
C Drag coefficient, dimension less
m Moisture content, per cent (w.b.)
M Moisture content, per cent (d.b.)
ρ_p, ρ_f Mass density of particle and fluid, $(kg-sec^2)/m^4$
V_t Terminal velocity, m/sec
W Weight of particle, kg
K Thermal conductivity, kcal/(m hr°C)

CHAPTER 2

Psychrometry

Introduction

Ambient air is a mixture of dry air and water vapour. In many unit operations moist air is necessary. To work out such problems it is essential to have a knowledge of the amount of water vapour present in air under various conditions, the thermal properties of such a mixture, and changes in the heat and moisture contents as it is brought in contact with water or wet solid. Particularly in grain drying, the natural or heated air is used as a drying medium. Although the proportion of water vapour in air is small, it has a profound effect on the drying process.

Problems in air-water vapour mixture which include heating, cooling, humidification, dehumidification, and mixing can be solved with the help of mathematical formulae. As these calculations are time consuming, special charts containing the most common physical and thermal properties of moist air have been prepared and are known as psychrometric charts. The psychrometric chart is, therefore, a graphical representation of the physical and thermal properties of atmospheric air.

The different terms used to express the physical and other thermodynamic properties of air-water vapour mixture are defined and discussed here.

Humidity

The absolute humidity, H is defined as kilogrammes of water vapour present in one kilogramme of dry air under a given set of conditions.

H depends upon partial pressure of water vapour, p_w in air and total pressure, P.