Principles of

CEREAL

Science and Technology

R. Carl Hoseney

Principles of

CEREAL

Science and Technology

R. Carl Hoseney

Department of Grain Science and Industry
Kansas State University
Manhattan, Kansas

Published by the
American Association of Cereal Chemists, Inc.
St. Paul, Minnesota, USA

Library of Congress Catalog Card Number: 86-070292
International Standard Book Number:
0-913250-43-0
0-913250-44-9 (student edition)

Printed in the United States of America

American Association of Cereal Chemists, Inc.
3340 Pilot Knob Road
St. Paul, Minnesota 55121, USA

Preface

The field of cereal science and technology is very broad and complicated. Cereals are complex biochemical entities that vary in composition and properties from year to year, from location to location, and from one cultivar to another. Cereal science is also complicated by the fact that the same raw material may be used to make different products. Therefore, the definition of "good quality" for a cereal such as wheat changes depending upon whether the wheat is used to make a loaf of bread or a cookie.

To understand cereals and their processing into products, the cereal scientist must be a jack-of-all-trades. He or she must understand chemistry (all areas), biochemistry, physics, engineering, and many other sciences. In addition, the scientist must also understand the "art" of the cookie baker and the brewmaster. Clearly, no one will accomplish all of these. Those of us who have mellowed with age in the field have long since reconciled ourselves to the fact that we cannot understand it all. We have forgotten how difficult this is for the new, bright, idealistic student to accept.

The purpose of this book is to provide such students with a basic background, something that they can stand on as they start their studies of how cereals work. In an attempt to accomplish that goal, the book is written as a text, not simply as a reference book. I hope that it will provide the student with the necessary background to understand the reference books listed at the end of the chapters. I also hope that the students using this book will find, as I have, that the study of cereal science is fun!

Many people allowed me to use their figures and data or gave permission for figures and tables to be reprinted. In the interests of simplicity, the credits for the figures are given in a section at the end of the book.

I would also like to thank many other people for their help with the book, particularly those students who have sat through my many hours of lecture and asked the key questions that made me realize that I was not explaining something clearly. I thank Kathy Zeleznak and Art Davis for their help with the figures, Judy Toburen for her typing, and Walter Bushuk and Y. Pomeranz for reviewing the manuscript.

R. Carl Hoseney

Contents

Structure of Cereals

CHAPTER 1

Members of the grass family (Gramineae), which include the cereal grains, produce dry, one-seeded fruits. This type of fruit is a *caryopsis* but is commonly called a *kernel* or *grain*. The caryopsis consists of a fruit coat or *pericarp*, which surrounds the seed and adheres tightly to a *seed coat*. The seed consists of an *embryo* or *germ* and an *endosperm* enclosed by a *nucellar epidermis* and a seed coat. The parts of the caryopsis of wheat are shown in Fig. 1. In general, all cereal grains have these same parts in approximately the same relationship to each other.

The caryopsis of all cereals develops within floral envelopes, which are actually modified leaves. These are called the chaffy parts or *glumes*. In rice and most cultivars of barley and oats, the floral envelopes cover the caryopsis so closely and completely that they remain attached to the caryopsis when the grain is threshed and constitute the *hull* of those grains. In wheat, rye, corn, grain sorghum, and pearl millet, the grain and hull separate readily during threshing and the grains are said to be naked.

Wheat

A caryopsis or kernel of wheat is diagrammatically shown in both longitudinal and cross section in Fig. 2. The kernels average about 8 mm in length and weigh about 35 mg. The size of the kernels varies widely depending upon the cultivar and their location in the wheat head or spike. Wheat kernels are rounded on the dorsal side (the same side as the germ) and have a longitudinal crease the length of the ventral side (opposite the germ). The crease, which runs nearly the entire length of the kernel, extends nearly to its center. The two cheeks may touch and thus mask the depth of the crease. The crease not only makes it difficult for the miller to separate the bran from the endosperm with a good yield but also forms a hiding place for microorganisms and dust.

Wheat kernels vary widely in texture (hardness) and color. The variation in texture, which appears to be related to binding forces in the endosperm, is discussed later. The color, usually white or red (although purple is also known), is related to pigment in the seed coat. The type and presence of the pigments is under genetic control and thus can be manipulated by the plant breeder to give the desired color.

- **Wheat kernel (caryopsis)**
  - **Pericarp (fruit coat)**
    - **Outer**
      1. Epidermis (epicarp)
      2. Hypodermis
      3. Remnants of thin-walled cells
    - **Inner**
      4. Intermediate cells
      5. Cross cells
      6. Tube cells
  - **Seed**
    - Seed coat (testa, spermoderm, tegmen) and pigment strand
    - Nucellar epidermis (hyaline layer, perisperm) and nucellar projection
    - **Endosperm**
      1. Aleurone layer
      2. Starchy endosperm
    - **Germ (embryo)**
      - Scutellum (cotyledon)
        1. Epithelium
        2. Parenchyma
        3. Provascular tissues
      - Embryonic axis
        - Plumule, including coleoptile
        - Primary root, covered by coleorhiza
        - Secondary lateral rootlets
      - Epiblast
  - **Bran**

Fig. 1. Parts of a wheat kernel.

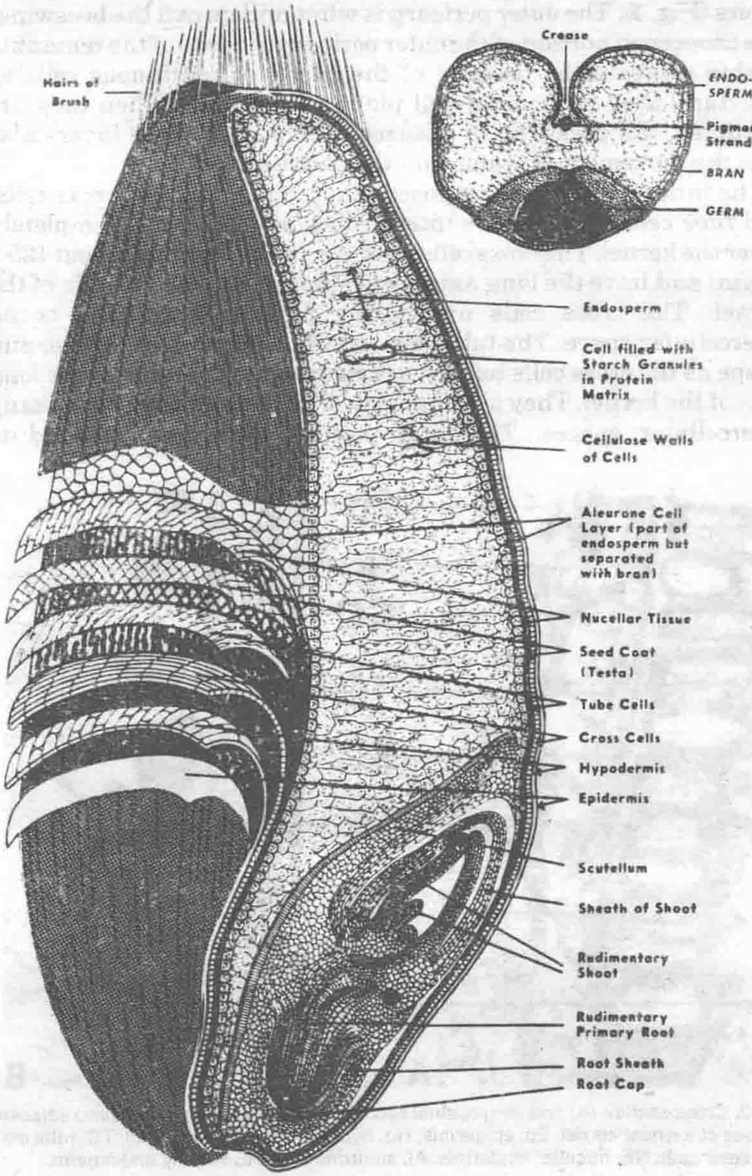


Fig. 2. Longitudinal and cross sections of a wheat kernel.

PERICARP

The pericarp surrounds the entire seed and is composed of several layers (Fig. 3). The outer pericarp is what millers call the beeswing. The innermost portion of the outer pericarp consists of the remnants of thin-walled cells; because of their lack of continuous cellular structure, they form a natural plane of cleavage. When they are disrupted, the beeswing is released. Removal of these layers also aids the movement of water into the pericarp.

The inner pericarp is composed of intermediate cells, *cross cells*, and *tube cells*. Neither the intermediate nor tube cells completely cover the kernel. The cross cells are long and cylindrical (about 125 × 20 μm) and have the long axis perpendicular to the long axis of the kernel. The cross cells are tightly packed, with little or no intercellular space. The tube cells are of the same general size and shape as the cross cells but have their long axis parallel to the long axis of the kernel. They are not packed tightly and thus have many intercellular spaces. The total pericarp has been reported to

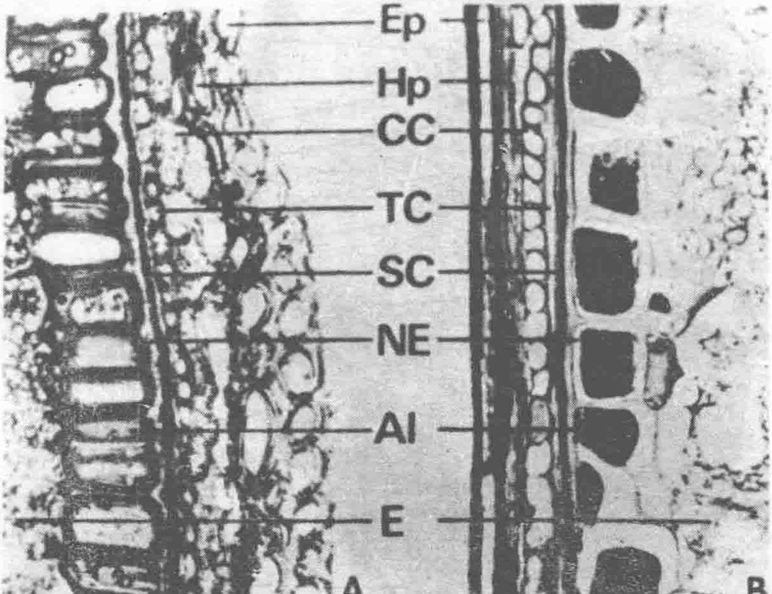


Fig. 3. Cross section (A) and longitudinal section (B) through the pericarp and adjacent tissues of a wheat kernel. Ep, epidermis; Hp, hypodermis; CC, cross cell; TC, tube cell; SC, seed coat; NE, nucellar epidermis; Al, aleurone layer; E, starchy endosperm.

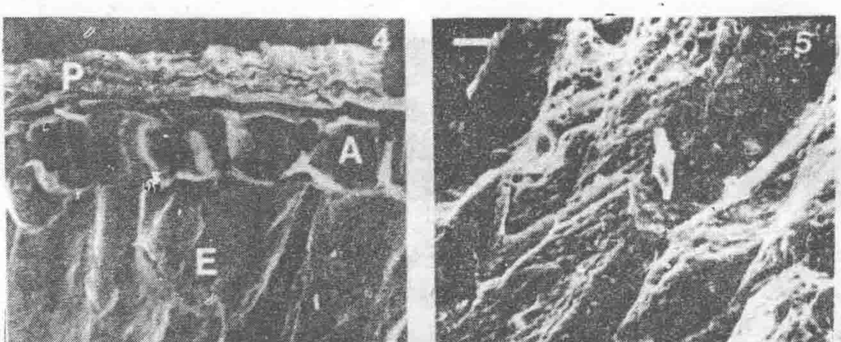
comprise about 5% of the kernel and to consist of approximately 6% protein, 2.0% ash, 20% cellulose, and 0.5% fat, with the remainder supposedly pentosans.

SEED COAT AND NUCELLAR EPIDERMIS

The seed coat is firmly joined to the tube cells on the outside and the nucellar epidermis on the inside. It consists of three layers: a thick outer cuticle, a layer that contains pigment (for colored wheats), and a thin inner cuticle. The seed coat of white wheat has two compressed cell layers of cellulose containing little or no pigment. The thickness of the seed coat varies from 5 to 8 μm. The nucellar epidermis, or hyaline layer, is about 7 μm thick and closely united to both the seed coat and the aleurone layer.

ALEURONE LAYER

The *aleurone layer*, which is generally one cell thick, completely surrounds the kernel, covering both the *starchy endosperm* and the germ. From a botanical standpoint, it is the outer layer of the endosperm. However, it is removed during milling, along with the nucellar epidermis, seed coat, and pericarp to form what the miller calls *bran*. The aleurone cells are heavy-walled, essentially cube-



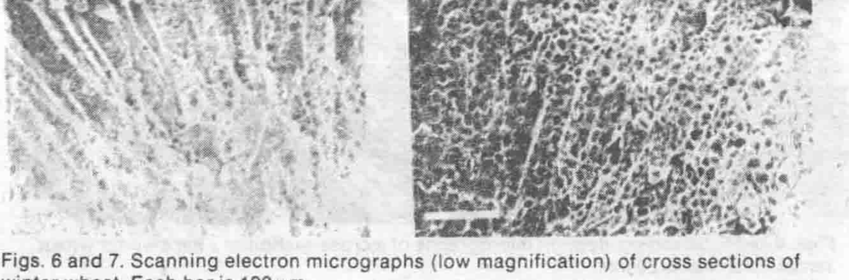
Figs. 4 and 5. Scanning electron micrographs of a cross section of a hard winter wheat kernel. Each bar is 20 μm.

4. Pericarp (P), aleurone layer (A), endosperm (E).
5. Endosperm cells.

shaped, and free of starch (Fig. 4). The average thickness of the cells is about 50 μm. The cell walls are 3–4 μm thick and have been reported to be largely cellulosic in composition. Aleurone cells contain a large nucleus and a large number of *aleurone granules* (Fig. 4). The structure and composition of the aleurone granules is complex. The aleurone layer is relatively high in ash, protein, total phosphorus, phytate phosphorus, fat, and niacin. In addition, thiamine and riboflavin are higher in the aleurone than in the other parts of the bran, and enzyme activity is high. Over the embryo, the aleurone cells are modified, becoming thin-walled cells that may not contain aleurone granules. The thickness of the aleurone layer over the embryo averages about 13 μm, or less than one third the thickness found elsewhere.

GERM OR EMBRYO

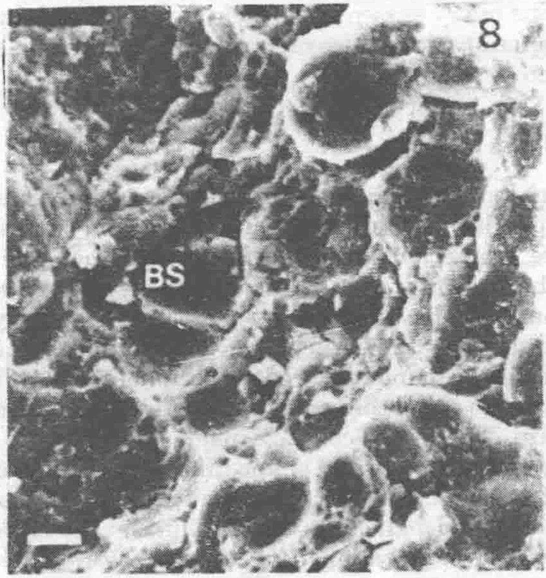
The germ of wheat comprises 2.5–3.5% of the kernel. As detailed in Fig. 2, the germ is composed of two major parts, the *embryonic axis* (rudimentary root and shoot) and the *scutellum*, which functions as a storage organ. The germ is relatively high in protein (25%), sugar (18%), oil (16% of the embryonic axis and 32% of the scutellum are oil) and ash (5%). It contains no starch but is rather high in B vitamins

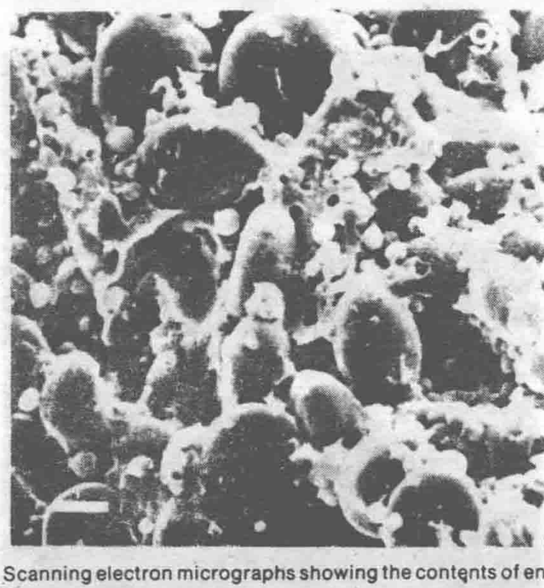


Figs. 6 and 7. Scanning electron micrographs (low magnification) of cross sections of winter wheat. Each bar is 100 μm.

6. Hard winter wheat with breakage at the cell walls.

7. Soft winter wheat with breakage through the cells.





Figs. 8 and 9. Scanning electron micrographs showing the contents of endosperm cells. Each bar is 10 μm.

8. Hard winter wheat. Note the broken starch (BS) granule.

9. Soft winter wheat.

and contains many enzymes. The germ is quite high in vitamin E (total tocopherol), with values ranging up to 500 ppm. The sugars are mainly sucrose and raffinose.

ENDOSPERM

The starchy endosperm, excluding the aleurone layer, is composed of three types of cells: peripheral, prismatic, and central. The cells vary in size, shape, and location within the kernel. The peripheral cells are the first row of cells inside the aleurone layer and are usually small, equal in diameter in all direction or slightly elongated toward the center of the kernel (Fig. 4). Several rows of elongated prismatic cells are found inside of the peripheral cells (Fig. 5). They extend inward to about the center of the cheeks and are about 150 × 50 μm in size. The central cells are inside the prismatic cells. They are more irregular in size and shape than are the other cells.

The endosperm cell walls are composed of pentosans, other hemicelluloses, and β-glucans but not cellulose. The thickness of the cell walls varies with location in the kernel; they are thicker near the

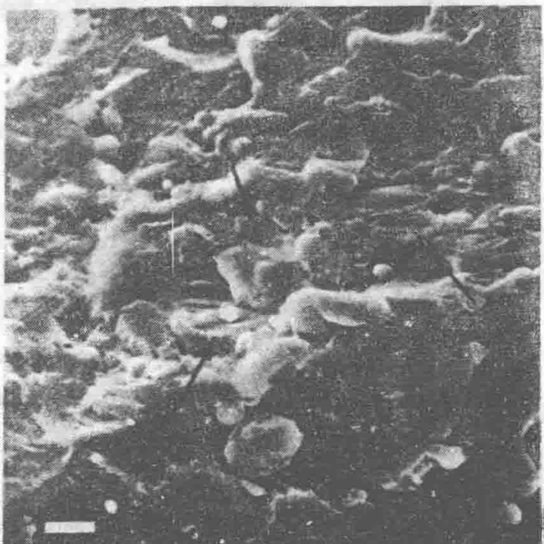


Fig. 10. Scanning electron micrograph of a durum wheat kernel, showing the contents of an endosperm cell. Note the large number of broken starch granules (arrows). Bar is 10 μm.

aleurone. Cell wall thickness also appears to vary among cultivars and between *hard* and *soft* wheat types (Figs. 6 and 7). The difference between hard and soft wheat may be the result of selection; hard wheats (bread wheats) have been selected for high water absorption. The hemicellulose in them absorbs large amounts of water. Thus, we are selecting for thick cell walls. In contrast, we do not want soft wheat flour to absorb large amounts of water, and thus we select for low water absorption and thin cell walls.

Another difference between hard (Fig. 6) and soft (Fig. 7) wheats is the point of fracture when the kernels are broken. With hard wheat, the first point of fracture occurs at the cell wall rather than through the cell contents. This is particularly evident in those cells just inside the aleurone. In soft wheats, the fracture occurs through the cell contents. This is evidence that the cell contents are more firmly bound to each other in hard wheats, resulting in a point of weakness at the cell walls. Of course, as the kernel is reduced to flour size, the hard wheat cell contents are also fractured.

The contents and cell walls of the endosperm cells make up *flour*. The cells are packed with starch granules embedded in a *protein matrix* (Fig. 8). The protein is mostly, but not all, *gluten*, the storage proteins of wheat. In maturing wheat, the gluten is synthesized in *protein bodies*. However, as the grain matures, the protein bodies are compressed together into a matrix that appears mud- or claylike, and the protein bodies are no longer discernible. The starch granules occur as large, lenticular (lens-shaped) granules of up to 40 μm across the flattened side and as small spherical granules (2–8 μm in diameter). In actuality, one can find granules of all sizes between these extremes, but these two sizes and shapes are preponderant.

Figure 8, which is of hard wheat, also shows the tight adherence of the protein and starch. The protein appears to wet (coat or adhere to) the starch surface very well. This is characteristic of hard wheats. Not only does the protein wet the starch well, but the bond between the two is strong. Evidence for the strength of the bond is the tendency of hard wheats to break at the cell wall rather than through the cell contents and the breaking through some starch granules (note the broken granule in Fig. 8) rather than at the starch-protein interface.

In a similar micrograph of soft wheat (Fig. 9), the appearance is quite different. The starch and protein are similar in appearance, but the protein does not wet the surface of the starch. No starch granules are fractured, as the bond between the protein and starch ruptures easily, showing that it is not strong.