WHEAT:
PRODUCTION AND UTILIZATION

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Preface

The significant aspects of wheat are stressed, especially aspects relating to its production and utilization. Particular emphasis is given to those areas of current interest and technological progress. This book is intended to be a source for all pertinent information on wheat.

A multidisciplinary approach was used to cover such areas as agronomy, biochemistry, chemistry, economics, engineering, food science, genetics, nutrition, and technology. Contributors were selected because they are authorities having a close and continuing acquaintance with wheat.

In organizing the book, the Editor allocated chapters to various contributors. Some did not use all their space; others slightly exceeded their allotment. Generally, good coordination and uniformity of chapter treatment were achieved because close personal contact was maintained with the individual authors during the preparation of their chapters.

Chapters were selected to give a broad coverage of the many subjects and disciplines concerned with the production and utilization of wheat. Another Editor could have easily chosen different chapters, changed page allocations, and shifted subject emphasis. The Editor attempted to create a book that would be useful to all those having a direct or indirect association with the grain.

The Editor expresses his utmost appreciation to the contributing authors who met his challenge. Also, all the industries, universities, and governmental agencies who allowed their employees to participate are commended.

Some other associates gave substantial help to the Editor throughout the preparation of this book: Wilma J. Bailey, George N. Bookwalter, Charles W. Blessin, Doris M. Davis, Robert J. Dimler, John E. Hodge, Wilbur C. Schaefer, James H. Sloneker, and Virginia Mae Thomas. Their services are duly acknowledged.

Career-service employees of the United States Department of Agriculture are expressing their own opinions in their contributed articles, and not those of the United States Government.

GEORGE E. INGLETT

March 28, 1973

Contents

G. E. Inglett

Wheat in Perspective

Wheat provides more nourishment for the people of the world than any other food source. Only in certain areas of developed countries, primarily in times of surplus, are some kinds of wheat used directly for feed. Also in highly developed countries, nearly 28% of wheat-milled products, bran, and shorts go into mixed feeds.

Origin of Wheat

The cultivation of wheat is thought to have had its origin in the Fertile Crescent of Middle East, bounded on the east by the Zagros mountain system, on the north by the Taurus Mountains, and on the west by the Mediterranean. Carbonized remains of wheat grains and imprints of grains in baked clay have been found in the Neolithic site of Jarno in northern Iraq having an estimated radiocarbon date of 6700 B.C. The process of domesticating wheat can probably be extended even further back in time (Aykroyd and Doughty 1970).

Wheat Plant

The wheat plant is a member of the grass family Gramineae. All wheats, wild and cultivated, belong to the genus *Triticum*. There are 14 commonly recognized species of *Triticum*. The species are divided into three subgroups—diploid, tetraploid, and hexaploid—based on the number of chromosomes in their reproductive cells.

Almost all the world's wheat is hexaploid, known botanically as *Triticum aestivum* L. em Thell. Its grain may be either hard or soft in texture and its color may be brownish red or white. While it is commonly baked into bread, the softer-textured varieties are used in pastry, crackers, cookies, and other bakery goods.

A tetraploid type, durum wheat (*Triticum durum* Desf.), is especially suitable for macaroni products. Its grain may be either white (amber) or brownish red in color (Reitz 1967).

Food Uses of Wheat

Bread is the principal food made from wheat. The leavened loaf is the major form in developed countries. Many other forms of wheat are found in both developed and the developing countries (Pomeranz

and Shellenberger 1971). Besides leavened bread, wheat flour is the major ingredient in most rolls, chapaties, crackers, cookies, biscuits, cakes, doughnuts, muffins, pancakes, waffles, noodles, pie crust, ice-cream cones, macaroni, spaghetti, puddings, pizza, bulgur, many hot and ready-to-eat breakfast foods, and baby foods. Flour is also a common ingredient in gravies, sauces, and soups as a thickener.

The baked foods industry for the U.S. in 1967 had a sales volume of $4.3 billion. Bread and bread-type rolls were $2.8 billion, or nearly two-thirds of the total sales (Schaus 1971). In the U.S. almost 75% of the bread purchased is white panbread, sliced and packaged in a plastic bag or wrapper. The remaining 25% is distributed evenly among the hearth breads, such as French and Italian; rye breads, including pumpernickel; and specialty breads, like raisin, potato, and whole wheat.

Bread and Health

Bread has been a basic food throughout the recorded history of civilized man. In modern times, it has been enriched with certain vitamins and minerals. Enrichment of U.S. bread with thiamine and niacin is credited with almost completely eliminating beri-beri and pellagra. Riboflavin and iron are nutrients that have also been adopted for enrichment of bread in the U.S. A 1965 USDA food consumption survey reported that nearly all (98%) white flour and bread consumed was enriched. Almost all the corn meal and grits

TABLE 1.1

CONSUMPTION OF PURCHASED BAKERY PRODUCTS IN U.S. HOUSEHOLDS, SPRING 1955 and SPRING 1965

Product	Quantity Per Person Per Week		
	1955 lb	1965 lb	Change %
Bread	1.41	1.32	-6
Other baked goods	0.60	1.00	+67
Crackers	0.14	0.18	+29
Rolls	0.11	0.19	+73
Biscuits, muffins	0.03	0.08	+167
Cakes	0.11	0.14	+27
Pies and tarts	0.06	0.10	+67
Doughnuts	0.04	0.05	+25
Cookies	0.11	0.24	+118

Source: Senti (1971).

(93%), macaroni products (94%), and rice (86%) were also enriched (Senti 1971). Many breakfast cereals, particularly the ready-to-serve products in grocery stores, have added nutrients, although no standards of enrichment are specified. The principally unenriched wheat foods consumed in the U.S. are commercially prepared biscuits, cakes, cookies, crackers, coffee cake, doughnuts, muffins, and rolls. Consumption of these store-bought bakery goods was 67% higher in 1966 than in 1955, when a similar nationwide food consumption survey was made (Table 1.1). These products should be considered as potential nutrient-carrying foods.

Celiac disease is an intestinal disorder associated with eating wheat. It is a rare condition in which the cilia of the small intestine are damaged or atrophied, with consequent impairment of nutrient absorption. The disease can be completely arrested by excluding gluten entirely from the diet. Although the wheat gluten is involved in the disease, the mechanism of action is not known (Aykroyd and Doughty 1970).

Dental caries are also ascribed to eating refined wheat flour in our modern culture, but no clear evidence can be found.

Wheat Production

World wheat output for 1971 is estimated at 304 million metric tons. A comparison of world wheat production with other cereals is shown in Table 1.2, and in majoring exporting countries in Table 1.3.

In the U.S., corn is the principal feed grain produced. Wheat, however, is the major cereal food grown. A comparison of the major cereals expressed in terms of acreage harvested, yield per acre, production, and farm value is given in Table 1.4.

TABLE 1.2

WORLD PRODUCTION OF PRINCIPAL CEREAL CROPS, 1960-1971

Crop	Average 1960-64[1]	Production, million metric tons 1969[2]	1970[3]	1971[2,3]
Wheat	232	287	288	317
Rye	32	28	25	29
Rice[4]	160	193	201	200
Barley	85	117	118	133
Oats	49	52	51	52
Corn for grain	195	258	253	291

[1] Anon. 1971B.
[2] Anon. 1972A.
[3] Preliminary data.
[4] Excluding Communist China and USSR.

TABLE 1.3

WHEAT PRODUCTION IN MAJOR EXPORTING COUNTRIES IN MILLION METRIC TONS, 1963-1972[2]

Country	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972[2]
Canada	19.7	16.3	17.7	23.0	16.1	17.7	18.6	9.0	14.4	14.5
Australia	8.9	10.0	7.1	12.2	7.5	14.8	10.6	8.0	8.6	5.9
Argentina	8.9	11.3	6.1	6.7	7.3	5.7	7.0	4.2	5.4	8.0
France	10.2	13.8	14.8	11.2	14.0	15.0	14.5	12.9	15.4	16.0
USSR	40.0	57.2	46.3	75.0	64.0	76.6	62.3	80.0	79.0	75.0
U.S.	31.2	34.9	35.8	36.0	41.4	42.9	39.7	37.5	44.0	42.0

[1] Anon. 1971C; Anon. 1972B; Anon. 1972C.
[2] Preliminary working estimate.

TABLE 1.4

MAJOR CEREAL CROPS OF THE U.S.: ACREAGE, YIELD, PRODUCTION, AND FARM VALUE IN 1970

Crop	Acreage Harvested Million Acres	Yield Per Acre Harvested Bu	Production Million Bu	Farm Value Million $
Corn	57.6	71.7	4,110	5,479
Wheat	44.3	27.8	1,378	1,870
Sorghum[1]	13.7	50.7	697	785
Oats	18.5	48.9	909	577
Rice	—	4,566[2]	83[3]	420
Barley	9.6	42.6	410	374
Rye	1.5	25.9	38	37

Source: Anon. 1971B.
[1] As grain.
[2] Pounds per acre.
[3] Million cwt.

Trends

The most impressive changes in modern times are: (1) increased production, particularly by the semi-dwarf varieties; (2) growth of international trade; (3) decline in consumption in industrialized countries; but (4) rising consumption in many other areas of the world.

The dwarf wheats covered in later chapters need ample fertilization and sufficient water. Among the challenges to be met by the new varieties are liability to attack by local parasites and, in mechanized countries, lack of storage facilities for fertilizers, seed, pesticides, and harvested grain. Because the breadmaking qualities of the dwarf varieties are not fully suitable, improvement is needed.

Wheat enters into international trade more than any other food. Principal wheat-growing countries, such as the U.S., produce it in great excess of their own needs. Therefore, a large proportion of the world's wheat is not eaten in the countries where it is grown. Wheat consumption varies widely around the world. Information on wheat consumption can be found for more than 120 countries in a published report by FAO (Anon. 1971A).

The U.S. contains some of the greatest wheat-producing regions in the world, and its wheat industry is highly efficient; but in the national diet wheat products occupy a position of less importance than in any other modern society. The characteristic diet of a prosperous nation contains large proportions of meat and other foods of animal origin, many kinds of fruits and vegetables,

TABLE 1.5

WHEAT FLOUR COMPARED WITH SOME FOODS: PER CAPITA CONSUMPTION, RETAIL-WEIGHT EQUIVALENT, U.S., 1954-1970

Food (Lb)	1954	1956	1958	1960	1962	1964	1966	1968	1970
Wheat flour	126	121	121	118	115	114	111	112	110
Flour and cereal products	155	150	150	147	146	144	143	144	142
Meat	145	155	140	147	147	156	151	162	164
Poultry	28	30	34	35	37	39	44	46	51
Fruit, fresh	101	95	90	90	81	77	80	77	81
Fruit, processed	46	49	50	50	50	46	49	51	54
Sugars and other sweeteners	106	108	107	109	110	112	113	116	120
Dairy products, including butter	403	409	398	384	376	374	371	364	354
Vegetables	202	203	199	201	196	194	195	201	202

Source: Anon. 1971B.

increasing proportions of sugar, and decreasing consumption of wheat flour. These trends can be traced in Table 1.5.

Wheat consumption is rising in many parts of the world. In North Africa and western Asia wheat is steadily replacing the coarse grains, particularly corn and barley. Elsewhere, dynamic trends indicate that wheat is an excellent food source and is held in the highest esteem.

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John W. Schmidt

Breeding and Genetics

Wheat was grown as a food crop in prehistoric times, possibly as early as 10,000-8,000 B.C. (Morris and Sears 1967). The earliest wheats used for food were probably of the non-free-threshing emmer types rather than the free-threshing durum, common, and club wheats of today. For thousands of years, the emmers appear to have been the dominant wheat in the Near East, the area where wheat originated. Neither the exact area of origin, nor the complete ancestry of wheat is known. Genetic diversity is greatest in Iran and bordering countries, and the ancestors of common wheat occur there. Therefore, this area is of importance in wheat germplasm preservation for the wheat breeder as well as for the wheat taxonomist.

Urban civilization can exist only when a high-energy food is available in quantity. Wheat was a major high-energy food for the urban civilization along the trade routes of the Fertile Crescent area of the Near East, of North Africa and of Europe. Early colonists brought wheat to the New World, and today wheat is a major crop far removed from its ancient origin, although it remains the major food staple in that area.

RELATIONSHIPS OF WHEATS

Species Development

Origin of Wheat.—The wheats of current commerce (durum, common, and club wheats) are products of natural hybridization of ancestral types, none of which is of commercial importance today. The best-known ancestor is einkorn (*Triticum monococcum* L.) partly because it at least has been grown under domestication, and partly because it looks more like present-day wheat than the others. However, some of the other ancestors have been equally important in the development of current wheats.

A considerable amount of information is available regarding relationship in wheat. *Triticum durum* Desf. is derived from a tetraploid hybrid of diploid *T. monococcum* (einkorn) and an unknown diploid wild grass, each of which contributed a set of 7

chromosomes (called a genome). Further natural hybridizations of a similar tetraploid with a 7-chromosome wild grass (*Aegilops squarrosa* L.) [*T. tauschii* (Coss.) Schmal] produced hexaploid wheats that gave rise to spelt, common, club and some lesser-known wheats. This may be summarized (over-simplified) as follows:

First stage

T. monococcum (einkorn) + related but unknown wild grass = emmer-like wheat

diploid	diploid	tetraploid
7 pairs of chromosomes	7 pairs of chromosomes	14 pairs of chromosomes
A genome	B genome	A and B genomes

Second stage

Emmer-like wheat + *Ae. squarrosa* (*T. tauschii*) = spelt or common wheat

tetraploid	diploid	hexaploid
14 pairs of chromosomes	7 pairs of chromosomes	21 pairs of chromosomes
A and B genomes	D genome	A and B and D genomes

The fact that these natural hybridizations occurred suggests that the three diploids listed above must be related. Because of this Morris and Sears (1967) followed Bowden (1959) in placing most of the *Aegilops* species with *Triticum*, and thus *Ae. squarrosa* becomes *Triticum tauschii.*

Einkorn (*T. monococcum*) is universally accepted as the supplier of 7 chromosomes (A genome) of the tetraploid and hexaploid wheats. In the mid-1940's, Kihara (1944) and McFadden and Sears (1946) separately reported research which showed that *Ae. squarrosa* (*T. tauschii*) also provided 7 chromosomes (D genome) of the hexaploid wheats. At this time, origin of the 7 chromosomes of the B genome is still in doubt.

Polyploid Series.—The above discussion suggests that wheat is a polyploid series composed of basic sets of 7 chromosomes called genomes. Einkorn (*T. monococcum*) supplies the A genome (7 pairs of chromosomes), an unknown diploid wild grass supplies the B genome (7 pairs of chromosomes), and *Aegilops squarrosa* (*T. tauschii*) the D genome (7 pairs of chromosomes).

Sears (1954) showed the close relationship of the 3 genomes, (1) by developing all 21 fully viable single-chromosome-deficient lines (aneuploids) in Chinese Spring wheat, and (2) by showing that the effects of a specific chromosome deficiency (loss of a chromosome) in one genome could be compensated for by adding a specific extra chromosome in either of the other genomes. Soon thereafter, Riley and Chapman (1958) showed that intergenomic

pairing (pairing of A's with B's or D's) was possible when the effect of a gene on one of the chromosomes was removed. On the basis of this research, Sears suggested that the interrelationship of 7 chromosomes of each genome of common wheat could be shown thus:

	Genome		
Chromosome number in each genome	A	B	D
1	1A	1B	1D
2	2A	2B	2D
3	3A	3B	3D
4	4A	4B	4D
5	5A	5B	5D
6	6A	6B	6D
7	7A	7B	7D

Genetic Duplication.—The presence of a polyploid series suggests that a genetic factor could be present up to 3 times, for example, in 3A, 3B, and 3D of common wheat. Nilsson-Ehle (1911) anticipated this as early as 1909-1911 in his reports of 3 factors for red kernel color in common wheat. This was substantiated by more recent research when a genetic factor for red kernel color was found to be located on each of the chromosomes 3A, 3B, and 3D. The presence of any one of these 3 genes produces a red kernel, and only the complete absence of all 3 produces a white kernel.

The multiplicity of genetic factors governing a trait in the hexaploid wheats has been a problem in genetic studies of such wheats. In wheat breeding it has both negative and positive effects. For example, most flour quality traits are controlled by multiple factors. Therefore, when a poor-quality but otherwise desirable wheat is crossed with a good-quality wheat, large numbers of offspring must be grown in order to recover some good-quality lines having in addition the other desired traits. However, on the positive side it should be pointed out that this allows the accumulation of genetic factors enhancing a desired trait. Further, it allows for the maintenance of something similar to the heterozygosity of a cross-pollinated plant in the self-pollinated wheat plant.

Growth Habit.—In the U.S. wheats are grouped into fairly well-defined spring and winter growth-habit types. However, on a world-wide basis, there are various intergrades between true springs that do not respond to vernalization (cold requirement) and true winters that have a well-defined vernalization requirement. As might be anticipated from the earlier discussion, there is at least one major factor for growth habit in each of the 3 genomes. Thus we have spring and winter forms among the diploid, tetraploid and hexaploid