WHEAT STUDIES

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DURUM WHEATS AND THEIR UTILIZATION

Carl L. Alsberg

Durum wheat, a distinct species, probably originated in Northern Africa, where it still predominates. Because some strains are resistant to rust and drought, it is grown in many semi-arid regions, for example, the Mediterranean basin, southeastern Russia, western Asia, British India, the Great Plains region of western Canada and of the northern United States, and Argentina. Elsewhere it occurs but is of slighter importance. It probably constitutes about 8 to 9 per cent of the world's wheat crop.

Because of its yellow color and its vitreousness, durum is the premier raw material for the semolina used in alimentary pastes of the macaroni type. Though its hardness varies with climate and variety, other things being equal, it is the hardest of all cultivated wheats. In recent years quantitative methods for evaluating its quality for macaroni have been developed. These measure color, mechanical strength, and cooking quality of macaroni. As bread wheats durums have been less esteemed, except in Russia, in part because most varieties yield denser and less porous loaves, in part because their flour is of creamy yellow color, a defect which can now be overcome by chemical bleaching.

When their price is favorable, durums now tend to be used by millers in western Europe as "weak filler wheats" to the extent of 10 to 20 per cent, for improved methods of tempering render them less difficult to mill. They have good "gassing" power and do best blended with wheats deficient in this respect. Except in regions where they are the principal wheat and the requirement of the natives with respect to baking quality is not great, they are never used alone for flour, not even in Russia. Their price does not parallel that of common wheat because of their special use for macaroni. Sometimes they bring considerable premiums, and sometimes they are discounted.

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DURUM WHEATS AND THEIR UTILIZATION

Carl L. Alsberg

Durum is a distinct species of wheat, *Triticum durum*. Most other wheats of present commercial importance are varieties of the "common" species, *Triticum vulgare*. These include hard red spring, hard red winter, soft red winter, hard white, and soft white. White and red club wheats, *Triticum compactum*, are important in some regions. Of negligible importance nowadays are some other species: spelt, emmer, rivet or cone, and Polish wheat (respectively, *Triticum Spelta, dicoccum, turgidum,* and *polonicum*).

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Durum may constitute about 8 or 9 per cent of the total world production of wheat. Only a few countries show separate crop statistics for this species. Data and estimates for a good many countries suggest that durum production in what we term the "world ex-Russia" may have averaged between 300 and 350 million bushels in 1932–36; but the basis for some of the estimates is slender, and they do not cover all of the countries in the area which produces durum. The part of the durum production that is significant for international trade and wheat prices probably seldom exceeds 200 million bushels.

Durum is essentially a wheat of semi-arid climates. It is also of importance where the soils tend to have an appreciable alkali or salt content or where rust is an important handicap on the growing of common wheat. Outside of what we call the world ex-Russia, durum is important in Iraq, Iran (Persia), and the USSR. Before the war, Russia was the largest producer, ordinarily harvesting 150 to 200 million bushels of durum annually. Part of this was raised in an area near the Azov Sea, much of it for export to Italy and other European countries; part was grown in the Volga regions and provinces to the east, and prized for domestic flour.

In the Near East, durum is the only wheat grown in some of the smaller countries (e.g., Syria, Palestine) and is important in Turkey and others. In French North Africa, durum averages about two-thirds of the wheat crop. In the southern parts of Italy, Spain, and Portugal combined, more is raised than in North Africa, though the percentages of the national crops are much lower. India also produces substantial quantities, though probably not over 12 per cent of the average crop.

In the decade 1921–30 the United States was an important surplus producer of durum in the spring-wheat states, with crops averaging 65 million bushels and once (1928) reaching 99 million. In subsequent years the production has been much smaller, averaging only 23 million in 1931–37. Indeed, in the past five crop years durum exports have been negligible, and in two of these years imports were substantial. In Canada, durum production has become increasingly important in Manitoba and some neighboring districts of Saskatchewan; the largest recorded crop of 1937, estimated at 25 million bushels, was exceeded only by that of 1928 when inspections totaled 26 million.

Durum is generally prized as material for the manufacture of semolina for use in alimentary pastes such as macaroni, spaghetti, and vermicelli, of which Italians are notably fond; and for such uses this species is typically preferred to other wheats. Some by-product flour emerges in the process of manufacturing semolina. To some extent durum is also milled into flour, and such flour is commonly used for bread in Spain, Portugal, and other parts of the Mediterranean basin, as well as in Russia. Generally elsewhere, it is not considered a satisfactory bread flour, but with sufficient price incentive it can be blended into flour acceptable for breadmaking. In India, at least, durum flour is used both for alimentary pastes and in other ways. In much lesser degree, durum is fed to livestock, sometimes to a considerable extent in the North American regions where it is grown.

Because durum is much used otherwise than for bread, its prices do not closely parallel prices of other wheats. This would be true even if there were free trade in wheat. Where supplies of the favored types (amber as compared with red) are inadequate to supply demands for seed use and for semolina, it tends to command high premiums over other types; but when the supply considerably exceeds demand for these uses, durum tends to fall to discounts such that some is diverted into bread flour and some into feed channels. Thus in 1936–37, when world supplies of durum were unusually small, it commanded exceptional premiums in the United States (then a deficit country) and also in Canada (a surplus producer). In 1937–38, when durum was relatively abundant, it brought moderate premiums in the United States, where supplies were deficient, while in Canada it fell to heavy discounts. On the other hand, Italy has in recent years maintained a fixed premium for durum over soft wheats in the domestic crop.

The peculiarities of durum as a plant and the special character of its principal uses appear to justify a study of these subjects, on which there is considerable though scattered literature. The present discussion rests in part upon as yet incomplete information on durum, country by country. This, and its role in world trade, are reserved for subsequent presentation.

I. THE DURUM WHEAT PLANT

Plant Characteristics

As they grow in the field, these wheats appear to one not familiar with their appearance as actually being barleys. Indeed, in German they are sometimes called *Gerstenweizen* (barley wheats).

Durum or macaroni wheats have a spring habit of growth, i.e., they do not stool or tiller much. According to Orlov,[1] however, "in the Caucasus—provinces of Dagestan, Baku" and "in Transcaucasia," winter forms occur together with spring forms.[2]

Where winters are mild as around the Mediterranean (France, Italy, Greece, parts of the Caucasus), durum is sown in the fall and has a sort of half-winter aspect. Typical regions with winter culture are met with rather seldom. They exist, according to Orlov,[3] in North Africa, Algiers, "the Caucasus—provinces of Dagestan, Baku; in Transcaucasia; in Turkestan—in the Transcaspian district; and in Persia — in the district Sumbarsk."

"The leaves are usually broad and smooth, but have a peculiar whitish green color and possess an extremely harsh cuticle."[4] The culms (stems or straw) of most varieties are solid throughout or at least in the upper internodes, although in some cases they are hollow with thick walls. However, varieties with hollow stems like those of *T. vulgare* do occur; they come predominantly from Russia.[5] Well-developed culms possess 5 or 6 internodes above ground, although forms no taller than common wheat do occur. As a rule, the clums are much taller than those of the common wheats, and hence the tonnage of green material produced per unit area tends to be great. This is perhaps one of the reasons

[1] A. A. Orlov, "The Geographical Center of Origin and the Area of Cultivation of Durum Wheat Tr. durum Desf.," *Bulletin of Applied Botany and Plant-Breeding, Scientific Journal of the Bureau of Applied Botany* (published in Russian by State Institute of Experimental Agronomy, Scientific Committee of the Board of Agriculture; title page, tables, and summary in English), 1922–23, Vol. XIII, No. 1, p. 391.

[2] Cf. also Filipchenko, "Tabassaransk Durum Winter Wheats. Winter Garnovka and Belotourka," *Zemledelcheskaia Gazeta [Agricultural Gazette]*, 1895, No. 58; P. M. Zhukovskiĭ, *Durum Winter Wheat*, reprint by Agricultural Department, 1922; both cited by Orlov, *loc. cit.*

[3] *Op. cit.*, pp. 445, 453; C. R. Ball and J. A. Clark, *Experiments with Durum Wheat* (U.S. Dept. Agr. Bull. 618, Mar. 13, 1918), p. 3.

[4] M. A. Carleton, *Macaroni Wheats* (U.S. Dept. Agr., Bur. Plant Ind. Bull. 3, Dec. 23, 1901), p. 10.

[5] F. Körnicke and H. Werner, *Die Arten und Varietäten (Handbuch des Getreidebaues*, Vol. I, Berlin, 1885), p. 65.

why in some regions (Australia) durum varieties are preferred to common wheats for hay.[1] The tall growth of durum is also advantageous where there may be a heavy growth of weeds, for the durum protects itself to some extent from being choked out by overtopping the weeds. Where wheat is harvested by combine, the tall growth of durum under these circumstances is of prime importance, as in parts of western Canada. There, "a dry midsummer may often be followed by rains which promote the growth of such plants as Russian thistle which may . . . . literally 'bury' any wheat that may have succeeded in making a growth."[2]

The tall growth and late ripening of durum may be the reason why, in the Punjab, it is "more attacked by birds than the ordinary wheats." The straw is stiff, so that it is possible for birds to perch upon it and, because it is tall, it ranges above all other wheats[3] and is more conspicuous. However, according to Rivière and Lecq,[4] the presence of the beard protects the ear to some extent from damage by birds and ants.

The ears or heads in all except one or two varieties (probably hybrids) are always bearded. Kuchumov[5] has produced beardless varieties by hybridization with beardless forms of *T. vulgare* and has obtained dozens of constant beardless forms of *T. durum*. He concluded that obtaining beardless forms as valuable as the best bearded varieties is a difficult task, and that the role of the beards in this species of wheat is apparently a very important one. The beards are said to render the ears less subject to scald (*échaudage*).[6]

The presence of beards has sometimes been a hindrance to growing durum. When it was first introduced in the United States, many farmers refrained from growing it because the long, stiff beards were such a source of discomfort in handling the crop. With the increasing use of harvesting and threshing machinery, this objection disappeared.

Most varieties have short, thick, compact heads, flattened along the sides rather than along the faces of the meshes, as in common wheats.[7] "The spikelets . . . . are two- to four-grained. The outer chaff is prominently and sharply keeled, and the inner chaff somewhat compressed and narrowly arched in the back."[8]

The grains are usually white, amber, or yellow, but sometimes red.

> . . . . the latter, when pale and flinty, are extremely difficult to distinguish from white or amber flinty grains. The typical form is somewhat narrow, tapering toward both ends, more or less laterally compressed, with a narrow dorsal ridge, and wanting in plumpness, the shallow furrow usually having flattish sloping sides; the cross section is more or less triangular.[9]

The grains are usually large. "In certain varieties, the grains are almost or fully as large as those of Polish wheat, and are sometimes mistaken for it."[10] They tend to be very hard and vitreous—indeed, they furnish the hardest of all wheats. However, when grown under more or less humid conditions, they may be starchy.

According to Dondlinger,[11] the root system seems to be more extensive in durum wheats than in other wheats, but the distribution and quantity of the rainfall has much to do with the spread of the root system of all wheats, so that this character is perhaps only an environmental response.

Every living organism is composed of cells, and within each cell is a nucleus which stains more deeply with certain dyes than the rest of the cell. This dark-staining material con-

[1] John Percival, *The Wheat Plant: A Monograph* (London, 1921), p. 208.

[2] Canada, Dept. Agr., Dominion Experimental Farms, Cereal Div., *Progress Report of the Dominion Cerealist . . . . on Cereal Work on Dominion Experimental Farms and Stations for the Years 1934–1937, Inclusive* (Ottawa, 1938), p. 24.

[3] Albert Howard and G. L. C. Howard, *Wheat in India, Its Production, Varieties and Improvement* (Calcutta and London, c.1909), p. 177.

[4] C. Rivière and H. Lecq, *Traité pratique d'agriculture pour le nord de l'Afrique; Algérie-Tunisie-Maroc-Tripolitaine* (Paris, new rev. ed., 1928), p. 390.

[5] P. V. Kuchumov, "Spring Wheat Selection on the Kharkov Experiment Station," *Selektsiia i Semenovodstvo* [*Selection and Seed Culture*] (published in Russian by People's Commissariat of Agriculture of the U.S.S.R., and other organizations), May 1938, VIII, 35–38, especially pp. 37–38.

[6] Rivière and Lecq, *loc. cit.*

[7] J. A. Clark, *Varieties of Durum Wheat* (U.S. Dept. Agr. Farmers' Bull. 1706, October 1933), p. 1.

[8] Carleton, *loc. cit.*

[9] Percival, *op. cit.*, p. 211.

[10] Carleton, *loc. cit.*

[11] P. T. Dondlinger, *The Book of Wheat, An Economic History and Practical Manual of the Wheat Industry* (New York and London, 1908), p. 13.

sists of long, slender pieces twisted together like bits of string in a ball of twine. When the cell divides, these unravel and then become recognizable under the microscope as distinct, long, slender bodies known as chromosomes. As cell division proceeds, the chromosomes split lengthwise, and the two sets of halves thus formed separate, each set forming the nucleus of one of the two new cells resulting from the division of the original cell. In consequence, each new cell has the same number of chromosomes as the cell from which it was formed. It possesses half of each chromosome present in the original cell, which by division has formed the two new cells. This "half" chromosome grows in turn to a whole chromosome.

However, in the formation of new germ cells —pollen and egg cells—the net result is different. New body cells, as we have seen, always have the same number of chromosomes as the cells from which they are formed. New germ cells, on the contrary, always have just half as many chromosomes as the body cells (roots, stems, leaves, etc.) of the same species. The common wheat, *T. vulgare*, has 42 chromosomes in its body cells and only 21 in its germ cells.[1] Fertilization takes place by the union of a pollen cell with an egg cell. It is obvious that in the fertilization of common wheat the resulting cell out of which a new wheat plant may develop has again 42 chromosomes, since the pollen cell and the egg cell each have 21 chromosomes. In durum wheat, however, the body cells have 28 chromosomes and the germ cells 14. Because they have different numbers of chromosomes, difficulties arise in crossing the two wheat species, and further difficulties are encountered in making back crosses with one or the other of the parent species. Since the chromosomes are the bearers of inherited characters, wheat breeders encounter difficulties in transferring desirable characters, e.g., rust resistance, from durum to other species of wheat and vice versa.

Nomenclature and Origin

The scientific name, *Triticum durum*, was given these wheats by the botanist Desfontaines[2] who obtained them from northwest Africa and recognized that these wheats are distinct from the common wheats, *T. vulgare*. In some localities of North America, durum was known as "goose," "wild goose," and "rice" wheat. In some countries, macaroni or durum wheat is known as "hard" wheat. Indeed, in France *blé dur*, in Italy *grano duro*, and in Spain *trigo duro* always mean macaroni or durum wheat. While in Germany *Hartweizen* has the same meaning, according to Jasny[3] some Russian common wheats are so hard they are confused with durum in Germany and some other countries. However, in many grain markets the adjective "hard" is commonly applied to those varieties of bread wheats which are of vitreous and flinty texture to distinguish them from durum or macaroni wheat which is usually even more vitreous and flinty. The hard bread wheats belong to the group of the common wheats, *T. vulgare*, from which macaroni or durum wheat is quite distinct. Because it would be ambiguous to apply the adjective "hard" to durum wheat, the term "durum wheat" is used in this study for *T. durum*, a term which has priority over the designation "macaroni." To be sure, the word "durum" is only Latin for "hard," but that makes it only all the more appropriate, since it thus carries its own meaning to those with a knowledge of Latin. Moreover, it is the term most widely used in North America.

According to Percival,[4] there is no evidence that durum wheats were cultivated in prehistoric times. However, their cultivation is ancient, for Percival examined a number of wheat grains found by Professor Flinders Petrie in the Graeco-Roman cemetery at Hawara (dating from about the first century B.C.). These were plump and similar to some forms of *T. durum* grown at the present day. According to Schweinfurth,[5] its cultivation in

[1] Percival, *op. cit.*, pp. 117 ff.

[2] R. Desfontaines, *Flora Atlantica* . . . . (Parisiis, 1800), I, 114.

[3] N. Jasny, "Der russische Weizen," *Landwirtschaftliche Jahrbücher*, March 1926, LXIII, 427.

[4] *Op. cit.*, p. 206.

[5] "Ägyptens auswärtige Beziehungen hinsichtlich der Kulturgewächse," *Verhandlungen der Berliner Gesellschaft für Anthropologie, Ethnologie und Urgeschichte*, 1891, pp. 649–69; "Über die von A. Aaronsohn ausgeführten Nachforschungen nach dem wilden Emmer," *Berichte der Deutschen botanischen Gesell-*

Egypt goes back a long way and the naked wheat of the ancient Egyptians, termed *coyo,* was durum. The first certain knowledge we have for modern times goes back only as far as the sixteenth century. Dodoens[1] obtained it at that time from Spain and the Canary Islands. He described and depicted it under the name *T. Typhinum,* but regarded it as a degenerate form of einkorn (*T. monococcum*). Indeed, later botanists confused it with einkorn or with *T. turgidum.* Desfontaines, as above stated, was the first to recognize it as a distinct wheat.

The geographical origin of durum wheat has not yet been exactly located.[2] Whereas, according to Vavilov,[3] the soft wheats, *T. vulgare,* definitely originated in southwestern Asia, durum probably originated in northern Africa. There all the original and endemic forms are met with. Of all parts of the universe, Africa occupies the first place in regard to the number of varieties of durum wheat found there. According to Orlov,[4] it contains all varieties of durum wheat described up to the present time.

> The geographical distribution of the race characters of durum wheat shows quite definitely that the whole range of variability of the characters of Tr. durum, the whole complex of varying hereditary characters, are concentrated in the district of North Africa. Out of 74 race characters of Tr. durum, ... 72 have been found and established in the district of Algeria, Egypt and Abyssinia; 55 in Europe; 51 in Asia.[5]

The farther from this center of variability that *T. durum* is found, the fewer always are the number of race characters occurring, and the smaller is the range of variability of the types found.[6]

> At the present time some forms of durum wheat are met with in all parts of the world, . . . the whole of North and South (Cape Colony) Africa, the Southern peninsulas of Western Europe, the South and East of European Russia, the Southern parts of the provinces of West Siberia, Turkestan, Persia, India, Beludjistan, Mesopotamia, Asia Minor, Syria, Palestine; in America the Western part of the Great Plain of the United States, the South-Western part of the States of Canada, the plains of Mexico, Brazil, Argentina, Chile and the South-Eastern part of the mainland of Australia.[7]

In some of these regions, durum wheat is an important crop; in others, it occurs but rarely. "In East Siberia, China, Tibet and Hindustan," as well as in Japan, it is "almost absent."[8] "In Europe and Asia no variety has been found as yet which has not been recorded for the African district."[9] South Africa (Cape Colony) has 9 varieties, Asia but 20 out of 34 forms, and European and Asiatic Russia, 19 varieties. There are no endemic forms in Russia.[10]

The most widely cultivated varieties are *hordeiforme, coerulescens,* and *melanopus,* each of which has a large number of established races.[11]

Cultural Characteristics

As pointed out above, *T. durum* does not tiller much, although varieties with more or less of a winter habit of growth have been described. As a rule, it tillers even less than common spring wheat,[12] and seeding should therefore be somewhat heavier than for common wheat. For South Dakota, 1.50 bushels per acre is recommended where 1.25 per acre of ordinary wheat is sown.[13] It is important that pure seed be used. Durum wheat may differ quite widely from common wheat in time of ripening, and there is considerable difference between the different varieties of durum wheat in this respect. When the wheats are mixed, it is very difficult to separate them.[14]

T. durum grows rapidly and in Canada is weaker in the straw than Marquis.[15] Hence, it tends to lodge more in wet seasons and then is difficult to harvest. For this reason, summer fallow is often not planted to it. Its heavy

schaft, 1908, XXVIa, 309–24; both cited by A. Schultz, *Die Geschichte der kultivierten Getreide* (Halle a.d.S., 1913), I, 61.

1 Cited by Schultz, *ibid.,* p. 51.

2 Orlov, *op. cit.,* p. 446.

3 N. I. Vavilov; cited by Orlov, *loc. cit.*

4 *Op. cit.,* p. 448.
5 *Ibid.,* p. 451.
6 *Ibid.*

7 *Ibid.,* p. 452.
8 *Ibid.,* Table 4, p. 384, and p. 450.

9 *Ibid.,* p. 449.

10 *Ibid.,* pp. 449–50.
11 *Ibid.,* p. 450.

12 Howard and Howard, *loc. cit.*

13 E. C. Chilcott, *Macaroni Wheat in South Dakota* (South Dakota Agr. Exp. Sta. Bull. 77, December 1902), pp. 8, 26.

14 *Ibid.,* pp. 9, 42.

15 Rivière and Lecq (*loc. cit.*), however, state that in North Africa its solid straw renders it less liable to lodging.

beards tend to give the ears a nodding habit, making it more difficult to bind.[1] Durum succeeds best as a spring crop. In most of Russia and in North America, the crop is sown in spring, "but in most of the Mediterranean region, with its mild climate, the crop is sown in autumn."[2] Where so sown, it may provide useful green herbage, which may be fed off lightly by stock during winter without damaging the yield of grain at harvest.

Durum wheat requires a dry, hot climate for satisfactory growth, the plant being easily damaged by frost. It possesses great power of resisting drought, giving fair yields where the rainfall is not more than 10 to 18 inches. This ability to withstand or evade drought is fairly well proven.[3] Some of the factors involved are rapid, vigorous growth, fairly early maturity, and some measure of actual resistance to drought. Crops have been raised in several semi-arid parts of the world where no rain has fallen between seedtime and harvest.

> Its growth is most prosperous, however, where a considerable proportion of the annual rainfall occurs during the early part of the growing season, a few good showers alternating with bright sunshine and a dry atmosphere resulting in the highest yield of grain of fine quality.[4]

As is "not so generally understood, it does not reach its maximum development, especially in quality, in localities or seasons of heavy rainfall."[5] If one examines the distribution of durum acreage over the world, one finds in general an inverse relationship between precipitation and quality as expressed in hardness and gluten content of the kernel. Thus in India the hardest wheat grows in the south, in Russia toward the southeast, in North America to the northwest. This is perhaps a hint that wherever and whenever it is desired to extend wheat culture into semi-arid subtropical zones or into tropical elevated tablelands, it is the durum wheats that promise best. It is not impossible that the failures in wheat growing that have been recorded in the past in the tropics are due in part to experiments in too humid climates, in part to neglecting to try durums in semi-arid areas. In the semi-arid subtropics the hazards of growing any crop are great, due to variability in precipitation, and this in itself demands a drought-resistant crop. Indeed, one of the principal advantages in growing durum in any semi-arid climate is the reduction of the risk even if on average over a period of years the yield is less than for common wheat. This is of especial importance for the subsistence peasant farmer who faces famine when he is subjected to crop failure in two successive years.

That durum is sensitive to a humid climate is probably the reason why in some regions and in some years in the same region common wheat outyields durum. A close correlation between yields and total annual rainfall, or even of total precipitation during the growing period, cannot always be traced. Not infrequently, with the same rainfall durum tends to outyield common wheat in some years or some regions but not in others. This is probably due to the distribution of the precipitation. The period of flowering is not the same for all the varieties of wheat grown in the same region. If at the time of flowering of common wheat there is cool and cloudy or rainy weather, while at the flowering of durum there are hot, dry winds, common wheat may outyield durum even when the total rainfall is more favorable for durum than for common wheat. These are environmental conditions that reduce the yield of any wheat, for it has been shown that at the time of flowering there is a very great increase in the transpiration of the wheat plant. When the weather is hot and dry and especially when there is wind, the rate of transpiration becomes so great the roots are unable to make good the loss of water. The plant becomes partly desiccated and permanently injured.[6]

[1] United Grain Growers, Ltd., *The Durum Wheat Situation* . . . . (Winnipeg, Feb. 1, 1932), p. 17.

[2] Ball and Clark, *loc. cit.*

[3] J. S. Cole, "Co-operative Cereal Investigations at Highmore," in *Report of Investigations at the Highmore Station for 1903* (South Dakota Agr. Exp. Sta. Bull. 84, April 1904), p. 10; Chilcott, *op. cit.*, pp. 7, 25.

[4] Percival, *op. cit.*, pp. 207–8.

[5] Cole, *loc. cit.*

[6] Cf. H. L. van de Sande-Bakhuyzen, *Studies on Wheat Grown under Constant Conditions: A Monograph on Growth, with Contributions on the Carbon and Nitrogen Content of the Wheat Plant*, by E. P. Griffing and C. L. Alsberg (Food Research Institute, Misc. Publication 8, Stanford University, California, 1937), chaps. vi and xxxiii, Section 4.

This is one of the reasons why flowering is a critical period in the life of the wheat plant, and why (as shown by Hooker[1]) cool, cloudy weather or even rain at the time of flowering is favorable, other things being equal, for heavy yields. Consequently, wheat sown at such a time that it is not in flower when hot, dry winds occur may give heavy yields, whereas the same variety of wheat sown in the same locality at a time which brings it into flower when there are hot, dry winds may fail.[2] Hence the advantage of carefully adapting the time of sowing to the local climate week by week, as first pointed out by Brounov.[3]

This hypothesis finds support in the observation of Talanov[4] that the ear formation (shooting) and flowering of many varieties in the majority of the locations where he made his observations occurred on hot days with low relative humidity and, not infrequently, with winds, which led to arrest of development, especially in varieties of *T. durum*. The poor yields were the result of an extremely small number of kernels per ear, while the quality of the grain itself was not impaired. Indeed, in all localities suffering from drought, the varieties of *T. durum* produced even lower yields than those of *T. vulgare;* sometimes the number of kernels was not more than 1 to 2 per ear. Sometimes many of the ears were quite empty. Drought in itself does not always thin the stand much. The amount of productive tillering, i.e., number of tillers bearing ears, Talanov[5] found to be lessened but not nearly enough to account for the reduced yield. While the number of kernels per ear was reduced relatively much more than the number of tillers, the absolute weight of each kernel was not much affected. High yields of durum are due in part to the greater absolute weight of its kernels.

And yet it cannot be doubted that *T. durum* tends to yield better in localities with scanty rainfall than *T. vulgare*. Probably one should distinguish between total available soil moisture and unfavorable conditions at a critical time like flowering. Durum would seem to be more resistant to scanty total precipitation than common wheat, whereas it may be more sensitive to hot, dry winds at flowering time. For such greater sensitivity at this critical period, there would seem to be a good anatomical basis—the long beard possessed by all the durums. An awned or bearded ear exposes a much greater surface to hot, dry winds than a beardless one. Other things being equal, it must transpire more, i.e., lose water faster, than a beardless ear, and theoretically a bearded wheat should be more liable to injurious desiccation in hot, dry winds than an awnless wheat. Future investigation may show that, in a climate in which hot, dry winds are not uncommon at wheat-flowering time, the possession of beards may be a distinct disadvantage for all wheats, durum as well as common.

That the adverse weather conditions just discussed reduce yields but do not much affect quality is not astonishing if one considers that the kernel parasitizes on the mother plant. It seems to be a rather general biological law that when the offspring draws its sustenance from the parent, the parent is sacrificed. Thus the fetus in an undernourished mother usually develops normally at the expense of her body tissues. So the kernels in the ear draw upon the wheat plant, for it has been shown that the wheat seed grows at the expense of material already elaborated in the plant.[6] This material is merely translocated. For this process water is necessary, and this the roots continue to supply. If the roots cannot

[1] R. H. Hooker, "Correlation of the Weather and Crops," *Journal of the Royal Statistical Society*, March 1907, LXX, Part 1, pp. 10–15, 21; cf. also C. L. Alsberg, "Forecasting Wheat Yields from the Weather: Elements of an Unsolved Problem," WHEAT STUDIES, November 1928, V, 11–20.

[2] Ball and Clark, *op. cit.*, p. 6.

[3] P. J. Brounov, *The Russian Bureau of Agricultural Meteorology. Meteorological Critical Periods and Crop-Growing. Agricultural Forecasting* (St. Petersburg, 1910), reviewed in *Bulletin of the Bureau of Agricultural Intelligence and of Plant-Diseases* (International Institute of Agriculture), April 1911, II, 794–96.

[4] V. V. Talanov, "The Best Varieties of the Spring Wheats," *Bulletin of Applied Botany and Plant-Breeding* (published in Russian by All-Union Institute of Applied Botany and New Cultures, State Institute of Experimental Agronomy; title page, tables, and summary in English), 1926, Supplement 29, pp. 205–6.

[5] *Ibid.*, pp. 215–16.

[6] H. L. van de Sande-Bakhuyzen, *op. cit.*, Part III.

get water because the soil moisture is inadequate, or if they cannot supply it fast enough to compensate for excessively rapid evaporation (transpiration), then either no seeds can be formed or the moisture stream must be directed into a few rather than into many seeds. Apparently, in the interest of the perpetuation of the species, it is the latter that happens. In consequence, the chemical composition of a small crop resulting from drought is not very different from that of a larger crop resulting from a sufficient but not superabundant supply of moisture.

Such considerations probably account for the observations of Tchingo-Tchingas[1] on the quality of the grain from irrigated and unirrigated plats of durum at two different stations. At one, the irrigated durum was of rather better quality than the unirrigated; at the other, the reverse results were obtained. At neither station were the differences great.

For the best yields of durum of high quality, it would seem that a soil rich in nitrogen is important. Moreover, durum does well—at least in North America—where the soil is alkaline. It would seem that in Russia it does well where the salt content[2] of the soil is appreciable, and does best on newly broken virgin soil. These traits have led Jasny[3] to regard durum as a pioneers' crop *par excellence.* Historically in Russia, durum has been grown on the periphery of wheat culture and has been replaced by common wheat in the older cultivated area as wheat has spread onto virgin soils.

Jasny, indeed, seems to suggest that a large mineral-salt content of the soil is favorable to durum. It may, however, be asked whether a high salt content is favorable or whether durum is merely more tolerant to salt than common wheat. In this connection, it should be noted that the salts of the semi-arid region of the Great Plains of North America are alkaline and contain carbonates, whereas those of the semi-arid regions of Russia are not always alkaline. Perhaps the seeming relation between soil-salt content and durum culture is merely accidental, for the soils of semi-arid regions tend mostly to be high in soluble salts. The truth may be that durum is grown in semi-arid regions because in them it does better than common wheat, despite the higher salt content of the soil of such regions.

Many varieties of durum wheat are somewhat resistant, and certain varieties are very resistant, to attacks of rust (*Puccinia graminis*). This seems first to have been pointed out by Carleton.[4]

> The varieties now grown commercially [in the United States] are subject to more or less infection on the sheaths and leaves, while the peduncle, or neck, often remains fairly free from such infection. This allows the development of a fairly plump kernel under rust conditions which cause serious injury to the common wheats . . . . On account of their ability to produce well in the presence of rust infection, they also are valuable and widely grown in the subhumid portions of the Dakotas and western Minnesota.[5]

Durum wheats are also more resistant to smut than the spring varieties of common wheats. Bunt, or stinking smut, *Tilletia foetens* and *T. tritici,* does not often affect durum wheat, although loose smut, *Ustilago tritici,* is found about as frequently on both.[6] "The spike or head in the durum wheats is so compact that it dries very slowly after rains or heavy dews." Hence durum is "susceptible to the attacks of scab (*Fusarium culmorum* (W. Sm.) Sacc.) and other imperfect fungi. These fungi sometimes affect durum wheat rather seriously."[7] Thus, much of the Canadian crop in some years contained "considerable percentages of black-tipped and otherwise blackened kernels," due to attack by the fungus *Helminthosporium sativum* "associated with at least two other fungi." "The

[1] K. M. Tchingo-Tchingas, "Milling and Baking Properties of the Wheat Varieties in U.S.S.R.," *Bulletin of Applied Botany, Genetics and Plant-Breeding* (published in Russian by Lenin Academy of Agricultural Sciences in U.S.S.R., Institute of Applied Botany and New Cultures; title page, illustration titles, tables, bibliography, and summary in English), 1931, Supplement 46, pp. 448–49.

[2] In this study, "salt" signifies mineral salts of various kinds, and not solely common salt (sodium chloride).

[3] *Op. cit.*, pp. 422–23, 431.

[4] M. A. Carleton, *Cereal Rusts of the United States: A Physiological Investigation* (U.S. Dept. Agr., Div. of Vegetable Physiology and Pathology Bull. 16, Sept. 27, 1899), pp. 33, 69.

[5] Ball and Clark, *loc. cit.*

[6] *Ibid.;* cf., however, Talanov, *op. cit.*, p. 213.

[7] Ball and Clark, *loc. cit.*

presence of very small percentages of completely discolored kernels" affects milling quality seriously. Such wheat, moreover, tends to mold more easily than undamaged wheat, and its germinative power is impaired.[1]

Some varieties of durum seem less susceptible to attack by certain insects. Talanov[2] found that certain varieties were less infested by *Phytophaga destructor* than the varieties of *T. vulgare*. This he attributes to the fact that they possess adherent ligules and auricles without cilia. Hence, he suggests it is more difficult for the larvae to penetrate from outside into the inner surface of the leaf sheath than in varieties in which the ligule juts out from the central leaf. He also found *T. durum* less susceptible to frit fly but more susceptible to *Lema melanopa*, perhaps because the leaves are glabrous (i.e., without hairs).[3]

In some regions where winter wheats do best but spring-sown wheats will grow, in the event of great damage to the winter-wheat crop in autumn or winter, the loss may be retrieved in some "measure by sowing durum wheat the following spring."[4] Eastern Washington and eastern Oregon are such regions, but there the common spring wheats yield better than durum.

In summary, then, the characters which have given the durum wheats their outstanding value are resistance to, or evasion of, drought and rust, enhanced by rapid and vigorous growth and fairly early maturity. Under certain climatic conditions these characteristics result in a uniformly higher yield than that of any variety of common wheat,[5] and their creamy color and vitreousness make them the preferred raw material for macaroni.

II. DURUM WHEAT GRAIN

Character of Kernel

There are many kinds and varieties of durum wheat and their qualities may be very different. The word "quality," when applied to durum, implies very different criteria of judgment according as bread-flour quality or macaroni-semolina quality is meant. In countries in which durum is used primarily as a bread wheat, whether by itself or in admixture with other wheat (Russia, Great Britain, *et al.*), it is compared with common wheat. In countries in which it is used primarily for macaroni, it is the standard with which other wheats are compared. Indeed, some kinds of durum may be much better relatively for macaroni purposes than for bread. In French North Africa, the varieties Tounzi, Hached, and Kahla are regarded as flour wheats, Mohamed-Ben-Bachir, Mahmoudi, and Hedba as semolina wheats.[6] The red durums, at least in America, tend to be of poor quality for making macaroni, although their crude protein content tends to be higher than that of other American durums which are good for macaroni.[7] In the United States, therefore, red durums are heavily discounted on the market. This was also true in pre-war Russia[8] and is true today in British India. Except in the special case of Rajputana, in central and southern India, white or amber durums such as *bansi*, *malwi*, *khandwa*, etc., generally command higher prices than red durums. Emmer (*khapli*) is on a par with durum in India, and in some sections occasionally commands a premium.[9]

Not merely does the grain of durum wheat vary with the variety, but it varies also with

[1] F. J. Birchard and T. R. Aitken, *Report on the Milling and Baking Characteristics of the 1931–32 Crop* (Canada, Board of Grain Commissioners, Dominion Grain Research Laboratory, Winnipeg, mimeographed, Oct. 15, 1931), pp. 8, 9.

[2] *Op. cit.*, p. 211.

[3] *Ibid.*, pp. 211–12.

[4] Ball and Clark, *op. cit.*, p. 20.

[5] V. V. Talanov, "The Regions of the Best Varieties of Spring and Winter Wheats of U.S.S.R.," *Bulletin of Applied Botany, Genetics and Plant-Breeding* (published in Russian by All-Union Institute of Applied Botany and New Cultures, State Institute of Experimental Agronomy; title page, illustration titles, maps, and summary in English), 1928, Supplement 32.

[6] Rivière and Lecq, *op. cit.*, pp. 395, 396.

[7] J. A. Clark, J. H. Martin, and R. W. Smith, *Varietal Experiments with Spring Wheat in the Northern Great Plains* (U.S. Dept. Agr. Bull. 878, Nov. 9, 1920), especially pp. 46–47.

[8] Cf. Jasny, *op. cit.*, pp. 424–25.

[9] *Report on the Marketing of Wheat in India* (Agricultural Marketing in India, Marketing Series 1, Delhi, 1937), pp. 87, 90–93.

the environment in which the plant was grown. Where rainfall is suitably distributed through the growing season and is abundant enough without being too heavy, the kernel may be exceedingly hard and contain as much as 22+ per cent of crude protein ($N \times 5.7$),[1] water-free basis. No doubt this happens occasionally in many places, but it seems to be not uncommon in certain parts of Russia, the regions of Ekaterinoslav and Samara, for example.[2] In the United States, varieties of the Kubanka group contain only from 13.4 to 16.0 per cent of crude protein.[3] Canadian durum tends to contain somewhat more crude protein[4] than that grown in the United States, while Algerian and Tunisian durum contains only 11.9 to 13.6 per cent.[5] The durums of British India vary greatly in hardness and crude protein content according to variety, the region where grown, and the season. Some of them contain as much as the American product; some even less than the Algerian.

According to Körnicke,[6] hardness and vitreousness are not a general character, although these traits are usual. Wittmack[7] found varieties in lower Egypt which were constantly white and mealy. The Howards[8] state that durum wheats tend to become soft in certain localities. From the context it is reasonable to infer that they may also be mottled. Mottling occurs in French North Africa, where such wheats with berries part hard and part soft are known as *blés mitadinés*. Grown experimentally in the very humid climate of England, durum tends to have opaque, starchy kernels, which, however, still have the hardness characteristic of the race, giving porcelain-like rather than starchy fractures.[10]

While the gluten content of all wheats tends in general to depend upon climatic conditions, durum wheats tend to be high in protein relative to other wheats by heredity,[11] provided they are given a soil with sufficient nitrogen content. In some areas (e.g., parts of Algeria and British India), their protein content is not strikingly large, while in others (e.g., Manitoba and the northwestern part of the hard spring wheat region of the United States), it may not be consistently greater than that of the hard bread wheats.

The fact seems to be that the vitreousness of this wheat depends upon the rainfall and climate. According to Jasny,[12] the sensitiveness of durum to moisture is so great that the best quality is in the wheat harvested during the full heat of the day, rather than early in the morning or late in the afternoon. LeClerc grew durum wheats in many different regions of the United States. He found that in arid and semi-arid regions the grains were flinty and rich in gluten (sometimes containing as much as 18 per cent of protein), whereas in humid regions or under irrigation the grain tended to be more or less soft and mealy and to contain less gluten. LeClerc analyzed 100 samples of United States durum and found an average of 14.7 per cent protein, or 2.5 per cent more than that of common wheat.[13] He also found that a wet season invariably tends to produce a low-protein grain.[14]

In general, durum wheats seem to yield a smaller percentage of bran than other wheats —at least in America, they yield less bran when milled than any other class of wheats. This may be due to the structure of the berry, or it may be due to the grain being harder so

[1] See also J. S. Shepard, *Macaroni Wheat. Its Milling and Chemical Characteristics* (South Dakota Agr. Exp. Sta. Bull. 82, December 1903), pp. 17–19, 23–26.

[2] Jasny, *op. cit.*, p. 427.

[3] Clark, Martin, and Smith, *op. cit.*, p. 43.

[4] W. F. Geddes and W. J. Eva, *The Fourth Protein Survey of Western Canadian Amber Durum Wheat, 1935 Crop* (Canada, Board of Grain Commissioners, Grain Research Laboratory, Winnipeg, mimeographed, Dec. 24, 1935), p. 4.

[5] A. Balland, *Céréales* (*Les Aliments . . . .* , Vol. I, Paris, 1907).

[6] Körnicke and Werner, *loc. cit.*

[7] L. Wittmack; cited by Körnicke and Werner, *loc. cit.*

[8] *Op. cit.*, pp. 231–32.

[9] Rivière and Lecq, *op. cit.*, p. 407.

[10] E. A. Fisher and C. R. Jones, *The Wheats of Commerce. I. General Considerations* (National Joint Industrial Council for the Flour Milling Industry [London], Technical Education Series, Pamphlet 9, November 1932), p. 39.

[11] Percival, *op. cit.*, pp. 19–20, 208.

[12] *Op. cit.*, p. 423.

[13] J. A. LeClerc, "The Effect of Climatic Conditions on the Composition of Durum Wheat," *Yearbook of the United States Department of Agriculture, 1906* (Washington, 1907), pp. 199–212, especially pp. 202–4, 211.

[14] *Ibid.*, p. 203; J. A. LeClerc and S. Leavitt, *Tri-local Experiments on the Influence of Environment on the Composition of Wheat* (U.S. Dept. Agr., Bur. Chem. Bull. 128, Apr. 20, 1910), p. 18.

that the miller is able to mill off the aleurone layer and the endosperm more perfectly from these very hard wheats than from softer ones.[1]

The quality of durum wheat for alimentary-paste manufacture depends not merely upon its vitreousness but also upon its color, those samples with the greatest proportion of yellow pigment being preferred. Color, like vitreousness, seems to depend upon hereditary traits of the variety, upon climatic and seasonal conditions, and upon locality. A given variety, by heredity superior with respect to color, may be poorer in color when grown in an unfavorable locality than another variety inferior by heredity with respect to color grown in a favorable locality.[2] In North Dakota, the best durum for macaroni is grown in seasons of normal temperature and precipitation, while in hot, dry seasons it is of inferior color for macaroni.[3] Different varieties grown over a period of years in the same locality of North Dakota were found to rank for macaroni purposes in the following order: Mindum, Kubanka-75, Akrona, Kubanka-132, Kubanka, N.D.R. 216, Nodak, Golden Ball, Monad.[4]

Chemical Composition

It is not necessary here to reproduce in detail the chemical composition of *T. durum* over its wide geographic range. It is sufficient to refer the reader to some of the pertinent literature.[5]

Unpublished results of analyses by the United States Bureau of Chemistry, of hundreds of samples grown in most of the states west of the Mississippi, indicate the following range of composition:

Moisture, 8–12%; ash, 1.30–2.35%; P_2O_5, 0.70–1.20%; fat, 1.10–2.40%; fiber, 1.70–2.85%; pentosans, 5.80–8.20%; nitrogen, 1.77–3.10%; invert sugar, 0.17–1.20%; cane sugar, 1.60–3.90%; weight per 1,000 kernels, 23.3–55.1 grams.[6]

In general, it may be said that durum wheat tends to contain more protein than any other wheat; where the environment is favorable, it exceeds all other wheats in this regard. Where or when environment is unfavorable, it may contain less than hard spring wheat. Since in all wheats there is an inverse relationship between protein and starch content, samples of durum that have a large protein content have a correspondingly low starch content and vice versa. Because this relationship carries over into the semolina and flour products made from high-protein durum, these possess a greater protein content than similar products made from common wheats. In most countries protein tends to be the most expensive element of the diet, hence durum products may be of considerable significance in the cost of national dietaries.

The fat content also tends to be greater than that of common wheats.[7]

[1] J. H. Shollenberger and J. A. Clark, *Milling and Baking Experiments with American Wheat Varieties* (U.S. Dept. Agr. Dept. Bull. 1183, Feb. 7, 1924), p. 79.

[2] C. C. Fifield, G. S. Smith, and J. F. Hayes, "Quality in Durum Wheats and a Method for Testing Small Samples," *Cereal Chemistry*, September 1937, XIV, 661–73.

[3] C. E. Mangels, "Cereals and Milling," in *Experiment Station Progress for the Four-Year Period July 1, 1931 to June 30, 1935* (North Dakota Agr. Exp. Sta. Bull. 286, November 1935), p. 39.

[4] Fifield, Smith, and Hayes, *op. cit.*, p. 662.

[5] For North Africa, France, Somaliland, Sudan, French Indo-China, see Balland, *op. cit.* For Russia, see Talanov, "The Best Varieties of the Spring Wheats," *Bulletin of Applied Botany and Plant Breeding*, 1926, Supplement 29; Tchingo-Tchingas, *op. cit.;* M. P. Neumann, "Zur Kenntniss der russischen Weizen," *Landwirtschaftliche Jahrbücher*, May 1926, LXIII, pp. 780–86; C. A. Flaksberger and R. J. Rozhevits, *Cereals: Wheat* (Lenin Academy of Agricultural Sciences, Institute of Plant Industry, *Flora of Cultivated Plants*, Vol. I, Moscow and Leningrad, 1935)—in Russian, with title page, table of contents, and preface in English; maps giving origins and directions of migration of the wheats over the world and protein content of wheats in different wheat-producing regions, and an extensive bibliography. For older literature, see T. Kosutány, *Der Ungarische Weizen und das Ungarische Mehl* (Budapest, 1907). However, earlier investigations rarely made it clear whether the varieties analyzed were durum or common wheat. For the United States, see F. A. Norton, "A Study of Durum Wheat," *Journal of the American Chemical Society*, August 1905, XXVII, 922–34; also the files of *Cereal Chemistry*. For Canada, see Balland, *op. cit.;* Canada, Board of Grain Commissioners, Grain Research Laboratory, miscellaneous reports on durum wheat for 1936 and subsequent years. For British India, see *Report on the Marketing of Wheat in India*, previously cited.

[6] J. A. LeClerc, "Macaroni Products," *Cereal Chemistry*, September 1933, X, 393.

[7] Balland, *op. cit.*, p. 91; A. Balland, "Observations générales sur les blés," *Comptes rendus hebdomadaires des séances de l'Académie des Sciences*, Dec. 28, 1896, CXXIII, 1303; Talanov, "The Best Varieties of the Spring Wheats" (cited above), p. 224, and Table 31.

Durum tends to possess a greater content of mineral matter than common wheat, and this too carries over into the semolina and flour. Noteworthy is the composition of the ash; it contains about as large a proportion of phosphoric acid as other flours, which indicates that the high ash content is not due to accumulation of a special kind of mineral matter but rather to greater accumulation of the normal mineral matter of wheat.[1]

Durum wheat flour also tends to have a relatively considerable sugar content.[2] According to Neumann,[3] the sugar is glucose and maltose. At any rate, when durum flour is subjected to autolysis (self-digestion) it produces more maltose than other flours.[4] This is probably due to the presence of a relatively large fraction of starch in a form that is readily available for the enzyme, "beta-amylase," which is present in the flour. It is not due to the presence of "alpha-amylase" or "amylo-kinase," of which durum flour contains very little or none.[5]

This presence of much starch available for attack by beta-amylase may be due to natural susceptibility of durum starch, for there is some evidence that unruptured durum-starch granules are more susceptible to the wheat berry's diastase than those of other flours. But it may also be due to the presence in such flour of a large proportion of ruptured granules. Such granules are more easily attacked by diastase than whole, intact ones. It is reasonable to suppose that since durum is so hard, and since more power is required to grind it than is required for common wheat, more starch granules are ruptured in milling durum flour than in milling common-wheat flour. However, whether or not this is the case awaits investigation. If it should turn out that durum flour contains more cracked starch granules than, say, hard-spring-wheat flour, then one would expect durum flour to ferment more rapidly, whether or not its starch were especially easily attacked by diastatic enzymes.

In any event the presence of fermentable sugar, or its speedy formation in the dough by beta-amylase from starch susceptible to attack by this enzyme, causes durum-flour dough to ferment quickly. These phenomena probably account for the great "gassing power" of durum flour. By this is meant that during fermentation much carbon dioxide is generated at a rapid initial rate.

Durum contains flavone and carotinoid pigments.[6] Its carotinoid content is greater than that of other wheats. It is due to this fact that flour from durum tends to be more yellowish or creamy in color than that from other wheat. While this yellow color is regarded as a defect for breadmaking, because most persons prefer dead-white bread to bread with a creamy tinge, it may in fact indicate superior food value. Carotinoid pigment is the mother substance from which an important vitamin is formed. It is possible that in this respect durum products may be of somewhat better food value than similar products made from other wheats with a lesser carotinoid content. However, this possibility awaits scientific investigation.

The gluten of durum is not identical with that of common wheat; durum flour yields a heavier and stiffer dough with comparatively less water than other flours. Despite these differences in behavior, there is no satisfactory evidence that the two varieties of gluten differ chemically.[7] The differences in physical behavior presumably result from differences in the colloid states of the two glutens, or in the electrolytes associated with them, or the like. There is some evidence for the existence of such differences in physical state. Thus it would seem that the peptizability of the glu-

[1] Neumann, *op. cit.*, pp. 781–82.

[2] Norton, *op. cit.*, p. 925; cf. LeClerc, "Macaroni Products," *Cereal Chemistry*, September 1933, X, 393.

[3] *Op. cit.*, p. 783.

[4] R. M. Sandstedt, M. J. Blish, D. K. Mecham, and C. E. Bode, "Identification and Measurement of Factors Governing Diastasis in Wheat Flour," *Cereal Chemistry*, January 1937, XIV, 17–34, especially pp. 19, 32–33.

[5] *Ibid.*

[6] "Carotinoids" is the generic term applied to green, orange, and yellow pigments which occur widely in most plants and to which they owe the green and yellow color of their leaves and other organs. See, for example, D. S. Binnington and W. F. Geddes, "The Relative Loss in Pigment Content of Durum Wheat, Semolina and Spaghetti Stored under Various Conditions," *Cereal Chemistry*, March 1937, XIV, 239.

[7] H. Vogel and C. H. Bailey, "A Study of Durum Wheats," *Cereal Chemistry*, March 1927, IV, 136–49.

ten in durum wheat is somewhat different from that of common wheat, and that this is related to the poor baking quality of many durum wheats.[1]

As already pointed out, there is also some evidence that the physical properties of durum-wheat starch are somewhat different from those of common-wheat starch. The swelling capacity of durum starch when gelatinized seems to be greater than that of hard-red-spring-wheat starch. Consequently it gives more viscous pastes. An exhaustive study of this question, taking the size distribution of the granules into consideration, remains to be made.[2]

Rask and Alsberg[3] have called attention to the similarity of durum- and hard-winter-wheat starches and pointed out that both these types of wheat are more suitable for macaroni than hard spring wheat. Mangels and Bailey[4] have pointed out the similarity of winter-wheat starches and durum starches when treated with different agents that gelatinize without heat.

III. UTILIZATION OF DURUM WHEAT

In General

Primitive peoples prepare many sorts of seeds by roasting or parching, which can be done directly upon flat stones without special cooking utensils.

Some tribes learned to make porridge by boiling ground-up seeds. For this practice fire-proof vessels, such as pots of clay, are not necessarily required. Boiling may be done by dropping hot stones into any sort of water-tight vessel filled with the food material suspended in water. Some of the Californian Indians used tightly woven baskets in this way. Down to recent centuries, porridge was a major cereal dish. So long as porridge remained the most general method of preparation, many types of seed, including cereals, competed on even terms in the diet. Presumably only availability and flavor were controlling.

The introduction of grinding simplified the preparation of porridge, but it also led to the baking of various sorts of cake from a mixture of meal and water. With the baking of cakes, the texture of the baked cake became an important consideration. Some seeds yielded tough, or dense, or hard cake, while others furnished a soft, or friable, or porous product. It is presumably at this stage of the evolution of the art of cookery that wheat, and to a lesser degree rye, gained its advantage. As is well known, wheat contains a mixture of proteins, termed gluten, which when wet is elastic and tenacious. In consequence, when mixed with water, wheat meal or flour yields dough instead of batter; and dough produces a more or less porous cake. This property of wheat early led to the use of leaven and to the production of leavened bread. With the spread of bread eating, wheat, in the areas where it would grow, began to forge ahead as compared with other seeds.

But with the introduction of milling and baking, distinctions began to be made between different kinds of wheat wherever a number of varieties were grown in the same region or where transportation became good enough for the wheats from different regions to compete with one another. The very hard, vitreous-grained wheats, whether of the durum or the common varieties, tended to fall into disfavor because they were quite difficult to grind in primitive mills or even between modern buhr-stones. Indeed, where wheat is consumed principally as flour, durum is not popular with subsistence farmers, because it is too

[1] R. H. Harris, "A Study of Gluten Protein Fractionation from Sodium Salicylate Solution. Part I. Durum Wheat Gluten Fractionation," *Cereal Chemistry*, September 1937, XIV, 695–707; cf. also C. E. Mangels, "Varietal and Other Variations in Peptizability of Wheat Flour Proteins," *ibid.*, March 1934, XI, 164–72.

[2] C. E. Mangels, "Some Effects of Heat Exposure on Wheat Starches," *ibid.*, January 1934, XI, 86–94; O. S. Rask and C. L. Alsberg, "A Viscosimetric Study of Wheat Starches," *ibid.*, I, January 1924, 7–26; R. A. Gortner, "The Hydration Capacity of Starch," *ibid.*, July 1933, X, 298–312.

[3] *Op. cit.*, pp. 24–25.

[4] C. E. Mangels and C. H. Bailey, "Relative Viscosities of Wheat Starches," *Industrial and Engineering Chemistry*, April 1933, XXV, 456–60; C. E. Mangels, "Varietal and Regional Variation in Properties of Wheat Starches," *Cereal Chemistry*, November 1934, XI, 571–85.

hard for the small country or peasant mill to grind satisfactorily.[1] Where durum or other hard wheat is important locally, much of it is still used in porridge and cakes of the flapjack or hardtack type which can be made from wheat meal more or less imperfectly bolted. In fact, today, much wheat is used in this way in North Africa and other Mediterranean regions, but much is also converted into flour even though this process is laborious.

Before the introduction of the roller-milling process in the late 1870's, millers preferred soft to hard wheats. Hard common wheats were heavily discounted and durum wheats, which ordinarily are the hardest of all wheats, were scarcely salable on the great grain markets of the world. With the coming of roller milling, hard wheats rose to a premium over soft wheats, since the new process permitted the bran and germ to be more perfectly removed from hard-wheat flour, resulting in a whiter product.

But bread is not the only way in which wheat came to be used in recent times. Other important forms are the so-called alimentary pastes. Where and when noodles were first invented is not clear, but the Chinese have had them for many years and they have long been an important food in much of British India. In China, there is probably no durum wheat, whereas it is of major importance in British India. Durum is especially suitable for making macaroni, whereas noodles are usually made from common wheat. Perhaps noodles and macaroni were introduced into Europe from the Orient, perhaps they were invented independently in Europe. In any event, the macaroni-spaghetti types of alimentary paste have long been important in the diet in Italy. Macaroni reached France from Italy, it is said, even before the time of Louis XIII.[2] Curiously enough, until recent times there has been little consumption or production of macaroni in some of the Mediterranean countries producing, like Italy, a relatively large volume of durum compared with that of common wheat—for example, the Levant, North Africa, and Spain.

Despite the fact that the bulk of the wheat of Spain is durum[3] and despite the fact that there was close political connection between Spain and Italy for several centuries, macaroni has never become of importance in the Spanish diet. That Italy alone of the durum-growing countries around the Mediterranean basin became an important producer and consumer of macaroni leads one to suspect that a special factor was at work. Possibly this is to be found in the belief in some quarters that, at least so far as Europe is concerned, noodles were invented, or first became popular, in Germany. If that be so, then it is entirely reasonable to assume that they were introduced into Italy in the course of one or the other early Teutonic invasion. Under the influence of the durum wheat available in Italy, the German noodle might reasonably be supposed to have evolved into the Italian macaroni.

In any event, in considering the utilization of durum wheat, we shall have to consider two distinct methods of utilization—in bread and bread-like products and in alimentary pastes. Since the term "alimentary paste" is cumbersome, we shall use instead the terms noodle and macaroni, macaroni including the very many varieties of sizes and shapes that have become popular in Italy.

As a Bread Wheat

Flour-milling quality.—Since durum is the hardest of all wheats, a durum-wheat mill consumes more power than a common-wheat mill.[4] In the laboratory, durum is harder to mill than common wheats.[5] The earliest commercial shipments of which there is record were rejected because it was impracticable to grind them in the mills then in use.[6] Indeed, because of their hardness and the brittle-

[1] Jasny, *op. cit.*, p. 427.

[2] LeClerc, "Macaroni Products," *Cereal Chemistry*, X, 383.

[3] According to Körnicke and Werner, *op. cit.*, p. 66.

[4] Statements are made by practical American millers that 20 per cent more power is required. These are supported by experience in British India. "It may be observed, however, that owing to the wear and tear on the rollers *durum* wheats are disliked by roller mills. The electric power used in power driven *chakkis* [stone mills] for grinding one maund of wheat is about 1.3 units for very soft wheats and 1.6 or 1.7 in the case of *durum* . . . ." (*Report on the Marketing of Wheat in India*, p. 65).

[5] Norton, *op. cit.*, p. 924.

[6] Körnicke and Werner, *op. cit.*, p. 66.

ness of the bran coat, durum wheats require far more careful tempering or conditioning than hard common wheats. As a rule they mill better if their moisture content is first raised about 2 per cent higher than is customary in America for common wheat. Also, they do well with a longer tempering time. Appropriate tempering not merely increases flour yields but also improves baking quality.[1]

Flour yields from durum wheat tend to be somewhat less than from common wheat.[2] However, Clark, Martin, and Smith[3] found that, experimentally milled, all samples of durum but one yielded more flour than Marquis, the predominant hard spring wheat of North America, grown in the same localities. Similarly, Mangels[4] found that, when milled experimentally, samples of Mindum and Kubanka grown in North Dakota were only slightly inferior to Marquis in flour-yielding capacity. Mindum and Kubanka gave a ratio of yield to test weight of 1.22 and Marquis of 1.23. Pentad, a red variety, was much inferior; its ratio was 1.16. Indeed, in one locality characterized by heat and drought the three durums averaged better flour yields than the common wheats of the same locality.[5] Russian investigators have recorded analogous results.

The discrepancy between the experience of commercial millers and laboratory chemists is probably due in part to the great variability of durum with respect to flour yield as compared with common wheats.[6] Thomas[7] found that flour yields from durum increase with weight per bushel as with other wheats, but not to as great a degree. Although the durum samples he milled averaged highest in weight per bushel, the average flour yield was next to the lowest, and hard red spring wheat, although lowest in weight per bushel, was next to the highest in average flour yield.

Knyaginichev[8] has shown that flour yields depend more upon the character of the crease of the berry than upon any other single factor hitherto studied. The greater the thickness of the berry in relation to the depth of its crease, the greater the flour yield. This correlation is greater and more variable in durum than in other classes of wheat. It is generally held that the bran coat of durum is thicker than that of common wheat, but according to Selivanov[9] and Knyaginichev[10] this is not always true.

Another reason for the discrepancy between the laboratory and the commercial mill is undoubtedly the difference in milling technique. The harder is any parcel of wheat, durum or common, the less significant are the results of small-scale laboratory milling tests.[11]

The treatment to which durum is subjected in the mills and bakeries of western Europe is not always appropriate, according to Jasny.[12] Durum must be subjected to a very high milling process.[13] Grinding, strictly speaking, is not so important as the purification of the mill stocks. Fine grinding (*Flachmahlen*) damages durum more than common wheat, a fact which should be taken into account in evaluating laboratory tests.

Since the milling of durum makes such large demands on skill and equipment, milling in Russia was, and perhaps still is, more highly concentrated in the durum-growing regions than elsewhere. In Russia durum is hardly ever ground as fine as flour. The

[1] E. F. Ladd and C. H. Bailey, *Wheat Investigations, Milling, Baking and Chemical Tests* (North Dakota Agr. Exp. Sta. Bull. 93, June 1911), p. 228.

[2] D. W. Kent-Jones, *Modern Cereal Chemistry* (Liverpool, 1924), p. 22.

[3] *Op. cit.*, p. 44.

[4] C. E. Mangels, "Studies on Test Weight and Flour Yielding Capacity of Wheats," *Cereal Chemistry*, March 1934, XI, 231–35, especially pp. 232–33.

[5] *Ibid.*, p. 234.

[6] L. M. Thomas, *A Comparison of Several Classes of American Wheats and a Consideration of Some Factors Influencing Quality* (U.S. Dept. Agr. Bull. 557, May 18, 1917), p. 6.

[7] *Ibid.*, p. 12.

[8] M. I. Knyaginichev, "The Connection between the Physical and Chemical Symptoms of Wheat Grain with the Yield of Flour," *Bulletin of Applied Botany, of Genetics and Plant-Breeding* (published in Russian by Lenin Academy of Agricultural Sciences in U.S.S.R., Institute of Plant Industry; title page, tables, charts, and summary in English), 1931, Vol. XXVII, No. 2, pp. 89–128, especially p. 127.

[9] F. Selivanov; cited by Knyaginichev, *op. cit.*, p. 123.

[10] *Loc. cit.*

[11] Jasny, *op. cit.*, p. 432. [12] *Ibid.*, p. 431.

[13] This common milling term means a process of making flour from grain by several successive grindings and intermediate sorting, instead of by a single grinding.

best products—known as *Kruptschatka*—are grits (German, *Griesze*) which are only a little finer than porridge grits (German, *Suppengriesze*). The flours obtained incidental to the production of *Kruptschatka* are finer than the latter but they are not really flour; they are known as *Dunste*, in German. Only the products from the end of the mill are real flours, though of very inferior quality. Jasny[1] regrets not to be able to say definitely whether durum will or will not stand grinding to flour.

In Russia durum is always ground by itself. Only the streams passing over the last rolls may be mixed with streams from common wheat. The reason is that it is not satisfactory to grind a blend of the large, very hard durum berries with the smaller and less hard common wheat berries. It does not pay to put common wheat through the long, complex milling system that is necessary to obtain the best results with durum.

Baking quality. — Like common wheat, durum tends to improve in baking quality with age and only begins to deteriorate after more than a year, though it varies in this regard and there are exceptions. Indeed, durum seems to be more variable in this respect than common spring wheat. This is also true of durum flours.[2]

The durums of the Mediterranean region and of the Western Hemisphere are defective in baking quality. Their gluten is less elastic than that of many common wheats. This is one of the factors causing loaves made from durum to be smaller in volume and tighter in texture than loaves made from good common wheats.[3]

Jasny,[4] however, has stated that many kinds of Russian durum yield flour of high quality. He believes that baking quality is to a large extent a function of gluten content: durums with very high gluten content make good bread. The poor baking quality of Canadian, United States, and North African durum he attributes to the fact that their gluten content, though often high as compared with common wheat, is not great enough, and is considerably less than that of the better durums preferred in Russia for bread flour. Indeed, Tsarist Russia had no appreciable semolina-milling industry.

The work of Russian investigators in recent years in part bears out the views of Jasny. Tchingo-Tchingas[5] has shown that with increase of the percentage of protein to an optimum (17 to 19 per cent) the baking qualities of spring and durum wheats improve, but when the protein quantity exceeds this optimum the baking quality, instead of showing further improvement, begins to decline. He also confirmed Jasny in that he found several strains of *hordeiforme* and one of *melanopus*, which when grown in favorable locations sometimes equaled good spring wheat in loaf volume.[6] However, he also stated: "The baking qualities of the durum wheats are, on an average, lower than those of the hard vulgare wheats."[7]

Moreover, Tchingo-Tchingas[8] found that each of the different characteristics—volume weight, flour yields, volume of loaf, and baking strength—was optimum in different varieties. No single variety was superior in all respects. One variety of *hordeiforme* and one variety of *melanopus* were among the best in three respects. One variety of *hordeiforme*, one variety of *melanopus*, one variety of *sivouska*, and Mindum were among the best in two respects. None of the wheats were tested for macaroni making. The American variety, Mindum, so highly prized for this purpose, was among the best in volume weight and flour yield; yet it was indifferent in baking quality. Acme, another American variety, was rather poor in all respects. In this context it is worth while pointing out that the criteria employed by Tchingo-Tchingas were flour-milling and baking quality, not macaroni-quality factors.

[1] Jasny, *op. cit.*, p. 433.

[2] C. E. Mangels, "Effect of Storage on Baking Quality of Common and Durum Wheats," *Cereal Chemistry*, July 1924, I, 168–78.

[3] Vogel and Bailey, *op. cit.*

[4] *Op. cit.*, pp. 428 ff.

[5] *Op. cit.*, p. 445.

[6] *Ibid.*, pp. 437–38; *The Wheats of Southeastern Russia with Respect to Milling and Baking Properties* (in Russian; Leningrad, 1922); cited by Jasny, *op. cit.*, p. 434.

[7] Tchingo-Tchingas, "Milling and Baking Properties of the Wheat Varieties in U.S.S.R.," *Bulletin of Applied Botany, Genetics and Plant-Breeding*, 1931, Supplement 46.

[8] *Ibid.*, pp. 454–55.

Saunders, Nichols, and Cowan[1] investigated the general question whether mixtures of flours from dissimilar wheats—they paid no especial attention to durum—gave better loaves than either component alone. In almost all cases they failed to observe this phenomenon: "Almost invariably the loaf produced . . . . was intermediate in quality (sometimes almost the exact mean) between the two loaves made from the original flours." They found a very few exceptions, however, and leave the question open. Kazaryan[2] seems to have settled this question—at least for Russian durum. He encountered many cases in which mixtures of durum with other flours exhibited greater baking strength than the means of the components. Wheats vary greatly in this respect. As he puts it:[3]

> the higher the baking qualities of a variety in pure condition, the more it improves these qualities in the mixture, in comparison to the mean arithmetical index for the originals; on the contrary, the lower the quality of the variety in pure condition, the lower the indexes of the mixture.

There are exceptions.

Kazaryan made no determinations of gassing power. It seems likely that the greatest improvement will be observed when durum flour is mixed with flour deficient in fermentable material or diastatic power or both, for durum flour seems often to possess a superabundance of both.

It is obvious, then, that the view widely held—at least in America—that durum is unsuited for breadmaking is unjustified, especially if it is used in blends. It has long been used in this manner to some degree on the continent of Europe. In recent years durum has been gaining ground everywhere in the flour-milling industry, in part because more millers are learning how to temper it properly, in part because the introduction of chemical bleaching processes has made it possible to overcome one of the principal obstacles to the use of durum flour, its yellow color. Moreover, bread made from durum flour is said to have a superior sweet flavor.[4] Used in a blend with common wheat, it is advantageous to temper it separately, since it requires different treatment. It is also advantageous, though not usual, to mill it separately and to blend the flours, as is (or was) the practice in Russia.

Apparently not enough attention has been paid to adapting the processes of doughmaking, fermentation, and baking to the special requirements of durum flours in testing and using them. They have usually been treated in the same way as common-wheat flour. Saunders, Nichols, and Cowan[5] found that the use of more than the usual amount of yeast for durum flour (as also for winter-wheat flour) was of scarcely any advantage. Possibly this is connected with the high sugar content of durum. They also found that durum flour behaved better at the lower (26.6° C.) of the two fermentation temperatures they employed as compared with the higher (31.1° C.). It gave the best results when the low temperature was combined with only a small amount of yeast and produced an inferior loaf when a larger quantity was added, the opposite of what occurred at the higher temperature of fermentation.[6] Under these conditions durum flours were as strong as any of those tested. Perhaps this is a hint how to handle durum flour in bread baking. Norton[7] suggested that it ought to be treated more like whole-wheat flour than like short-patent flour. According to Kozmin,[8]

> when the doughs are somewhat stiff they do not rise properly, and the bread obtained is heavy and poor of texture. Yet, when water is used in sufficient quantity, the volume, weight, and texture of durum breads are not below those prepared with ordinary wheat flours.

[1] C. E. Saunders, R. W. Nichols, and P. R. Cowan, *Researches in Regard to Wheat, Flour and Bread* (Canada, Dept. Agr., Experimental Farms Branch, Cereal Div. Bull. 97, 1921), p. 28.

[2] S. Kazaryan, "Baking Properties of Wheats in Mixtures," *Bulletin of Applied Botany, of Genetics and Plant-Breeding* (published in Russian by Lenin Academy of Agricultural Sciences in U.S.S.R., Institute of Plant Industry; title page and summary in English), 1931, Vol. XXVII, No. 2, pp. 1–87.

[3] *Ibid.*, p. 85.

[4] M. A. Carleton and J. S. Chamberlain, *The Commercial Status of Durum Wheat* (U.S. Dept. Agr., Bur. Plant Ind. Bull. 70, Oct. 7, 1904), p. 48.

[5] *Op. cit.*, pp. 13–14.

[6] *Ibid.*

[7] *Op. cit.*, p. 929.

[8] P. A. Kozmin, *Flour Milling . . . .*, translated by M. Falkner and T. Fjelstrup (London, 3rd ed., 1921), p. 57.

According to Jasny,[1] durum, especially the *Kruptschatka* form, requires a longer fermentation time than common-wheat flour, in part because *Kruptschatka,* due to its texture, ferments slowly.

Like other wheats, durums vary in baking quality with variety and the locality where grown. Saunders, Nichols, and Cowan[2] found Canadian durums to vary in baking strength from very high (selected strains of Kubanka and Belotourka) to very low (Red Indian, Roumanian). Muraviev[3] obtained analogous results.

In speaking of quality in durums it is necessary to specify whether baking quality or quality for macaroni is meant. The factors that make for large volume of loaf desired in breadmaking seem to be, or to be associated with, qualities which do not contribute to the best macaroni quality. There seems to be no significant relation between color, so important for the macaroni maker, "and yield of straight flour, water absorption, weight of loaf, texture of crumb and ash of flour," all of which are important to the miller and the baker. Indeed, yellow color is a disadvantage in bread.[4] It follows that the wheat breeder, if he wishes to produce varieties of higher flour yield and baking qualities, as in Russia, follows objectives different from those he follows in America where his purpose is to improve varieties for macaroni making. In the early days, while durum varieties were being introduced into the United States, the importance of this distinction was not always realized. Durums were bred for rust resistance, drought resistance, yield, and flour-milling and baking quality. In more recent years breeders have substituted yellow color for flour-milling and baking quality, since in America durum has never come to be much used as a bread flour even in blends.

To the commercial baker the "absorption" of a flour, that is, the amount of water it requires to furnish dough of the proper consistency, is of great importance. The more it absorbs and the more it retains after baking, the greater the number of loaves the baker obtains. In this respect it has long been known that durum flour ranks high. Saunders, Nichols, and Cowan,[5] for example, found that Canadian durums absorbed much water (74 per cent) in doughing and retained much more in the baked-out loaf (50.3 to 53.7 per cent). According to Tchingo-Tchingas,[6] durum yielded 4.3 per cent more dough than common-wheat flour and 3.0 per cent more bread.

Up to a few years ago, British millers did not regard durum wheats as a class suitable for bread flour. The difficulty was perhaps not so much in the wheat as in conditioning. Today the improvements in conditioning machinery have made its use more extended. In England and on the Continent, millers are used to dealing with difficult and hard wheats of the durum type and, because milling is done at higher moisture contents than in America, millers are able to temper or condition these wheats over longer periods so as to get them into reasonable milling condition.

Durum wheat, the new crop of which tends to reach England in October,[7] is regarded by British millers as a substitute for "weak" wheats, such as Danubian or English[8]—and this despite its very high gluten content. The place of the United States and Canadian (Manitoba) durum in British flour milling has been set forth admirably by Fisher and Jones.[9] It

has traits which are peculiarly interesting from the point of view of blending, especially as it occasionally enters into some flours in quite considerable proportions. Let us deal with its good points first. Addition of Durum to a blend produces little noticeable change at doughmaking; the dough, however, may tend to fall off unduly in body as fermentation proceeds, though it in-

[1] *Op. cit.*, p. 434.

[2] *Op. cit.*, p. 27. Although the authors give a lower figure for Huguenot B (82) than for Red Indian (84), Huguenot B is probably not a true durum.

[3] P. A. Muraviev, "The Quality of Grain of Spring Wheat from the World Collection," *Selektsiia i Semenovodstvo* [*Selection and Seed Culture*] (published in Russian by People's Commissariat of Agriculture of the U.S.S.R., and other organizations), April 1938, VIII, 33–36.

[4] J. A. Clark, "Improving Quality of American Grown Durum Wheat," *Macaroni Journal*, July 15, 1924, VI, 21–23, especially p. 23.

[5] *Op. cit.*, pp. 13–14.

[6] *The Wheats of Southeastern Russia with Respect to Milling and Baking Properties;* cited by Jasny, *op. cit.*, p. 435.

[7] Fisher and Jones, *op. cit.*, p. 18.

[8] *Ibid.*, p. 20.

[9] *Ibid.*, pp. 26–27.

variably works excellently, a consequence, of course, of the excellent gassing power of the wheat. These qualities may be responsible for marked improvement in flours which have been on the tough side and deficient in gassing power as a result of abundance of high-grade Manitobas. Benefit to all-round crumb quality (particularly the production of a beautifully silky texture) usually attends the introduction of moderate amounts of Durum into a blend. Incidentally no miller could use this wheat and be sure of selling his flour were it not that modern bleaching processes permit the removal of the yellowish colour characteristic of flour from Durum wheat.

The appearance of Durum on the market [in the United Kingdom] is possibly a danger sign, however, when low-grade frosted Manitoba wheat has been plentiful. It may just "tip the balance" with many flours, bringing the typical "gumminess" into unwelcome prominence. The arrival of the wheat is also to be feared if the new English crop is of poor quality, because the combination of the two may produce a tender dough which rapidly deteriorates in handling properties before fermentation has gone far.

The amount to be used in a blend depends upon the price. It is not necessary to British flour millers, but they can use up to 10 to 15 per cent if it is cheap relative to other wheats. The extent to which it will be used in a blended flour depends upon its commercial value relative to other wheats. In determining this commercial value, the miller has to take into consideration that the flour yields of durum wheats tend to be somewhat less and the cost of milling somewhat more than for common wheat of the same test weight and moisture content.

It is stated that, in consequence of its high moisture content, bread from durum flour keeps fresh for a longer period than common-wheat bread.[1] Certainly it dries out a little less rapidly.[2] But losing moisture is not identical with growing stale; indeed, it has been doubted that these two phenomena have any direct relation.[3] Carleton and Chamberlain[4] had a large number of persons judge in blind tests the rate of growing stale of durum bread in comparison with hard-spring-flour bread, with the result that 100 of them found the durum bread fresher, 60 expressed the reverse judgment, and 39 found no difference. It is obvious the question needs investigation by some precise objective method.

Mixtures of red durum with *T. vulgare* or common wheat are neither better nor worse than with amber durum. There was formerly a fairly extensive market in Central Europe for red durum at the low level of prices at which such wheat could then be sold. This market has since very largely disappeared because of the price situation and import barriers of various sorts. However, the red durums were found to be entirely adequate for the purposes for which they were then purchased, namely, to serve as low-priced, medium-strength, filler wheat.[5] They vary, as do other wheats, in baking quality. Indeed Muraviev[6] found one red durum of the *affine* variety from Algeria which when grown at Odessa yielded flour of very high baking quality for a durum. Such wheats gave a dark flour because of a special structure of the grain coat.

For Alimentary Pastes

Although durum is not regarded as a high-quality wheat for breadmaking it is the premier raw material for the manufacture of macaroni and similar alimentary pastes which we shall include under the term "macaroni." The traits of durum that are disadvantageous for bread are advantageous for macaroni. The heavier, stiffer, and gluey texture of durum dough is liked in macaroni making. Less water is required; this is a disadvantage in the eyes of bakers but the reverse for makers of macaroni, which is a very dry product, and water used in its manufacture has subsequently to be dried out. The yellowish color is demanded in macaroni—in fact, European consumers consider white macaroni inferior.

Unlike bread, macaroni is not made from flour but from "semolina," although the poorer qualities may also be made from flour.

Semolina (French, *semoule;* Italian, *semolino*) is the term commonly applied in the trade to the durum-wheat product correspond-

[1] Percival, *op. cit.*, p. 208.

[2] Carleton and Chamberlain, *op. cit.*, pp. 46–47.

[3] C. L. Alsberg, "The Stale-Bread Problem," Wheat Studies, February 1936, XII, 221–47, especially pp. 240–43.

[4] *Op. cit.*, pp. 49–58.

[5] C. H. Bailey, personal communication.

[6] *Op. cit.*, p. 34.

ing to that known in the milling of common wheat as purified middlings or farina. The official U.S. definition for purified middlings is:

The granular product obtained in the commercial process of milling wheat, and is that portion of the endosperm retained on 10 XX silk bolting cloth. It contains no more flour than is consistent with good commercial practice, nor more than 15 per cent of moisture.[1]

The National Macaroni Manufacturers' Association has suggested the following definition: "Semolina is the purified middlings obtained from the grinding of durum wheat. It is free from bran and other offal and shall contain not more than 13.5% moisture and not more than 1% flour."[2]

Before the advent of modern roller milling, semolina was made in the household or in buhrstone mills as is still the practice in British India. In central and southern India and in a few parts of northern India, semolina (*rawa* or *suji* in the vernacular) is prepared on a small scale by means of hand stone mills, known as *chakkis*. The procedure is as follows:

The wheat is first soaked in water for a period of from 6 to 12 hours to facilitate the removal of the outer skin (bran). It is then partially dried —not in the direct rays of the sun—and subsequently ground. The ground product is gently rubbed on a piece of thin cloth tied tightly over the open end of a basket or sieved through a fine muslin cloth. The finest granules pass through and the larger products remain on the surface of the cloth. These are in turn separated into semolina (*suji*) and bran by winnowing. These operations are exclusively performed in the household as and when required.[3]

Semolina is never made on larger power-driven *chakkis*. It is possible to produce semolina with them, but the type of semolina produced by the modern roller mills has a better appearance and is generally preferred.[4]

In western countries, however, semolina is produced only in roller mills. This is not the place to describe the semolina-milling process in detail.[5] It is sufficient to point out that for the manufacture of semolina durum requires a more perfect cleaning system for the grain than common wheat, a longer break-roll system, a more elaborate middlings-purifying system, but a very much shorter reduction (smooth-rolls) system than is usual in the ordinary flour mill.

Every effort is made to obtain the largest possible proportion of semolina with as little flour as possible. The semolina may be conveyed by belts to reduce the production of flour by abrasion. Good durum should yield from 62 to 63 per cent of semolina, from 16 to 17 per cent of clear flour, and from 21 to 22 per cent of feed.[6] It is doubtful, however, whether American mills as a group do as well as this. It is probable that their flour production is about 19 per cent of the wheat ground. In French mills at the turn of the century, "yields of 60 and 65 per cent of high-grade semolina were not uncommon, with flour production as low as 12% to 15%."[7] Today many European mills seem to do better, producing as little as 10 to 11 per cent of flour.[8]

Of course, yields vary appreciably with the quality of the wheat. The highest yields of semolina are obtained from the hardest and most vitreous wheats, such as formerly came from Russia. Next come durums from Canada, then durums from the United States. Wheats from North Africa are very variable in quality and not well graded; some are quite starchy and yield correspondingly less semolina. The durum grown in France from imported seed, known as *métadiné*, is the starchiest of all and may yield as little as 30

[1] *Definitions and Standards for Food Products for Use in Enforcing the Food and Drugs Act* (U.S. Dept. Agr., Food and Drug Administration, Service and Regulatory Announcements, Food and Drug No. 2, 5th rev., November 1936), p. 7.

[2] F. L. Zerega, *Proposed Tentative Definitions for Semolina and Farina* (National Macaroni Manufacturers' Association, Washington Office, mimeographed, Mar. 8, 1927); cited by LeClerc, "Macaroni Products," *Cereal Chemistry*, X, 393.

[3] *Report on the Marketing of Wheat in India*, pp. 296–97.

[4] *Ibid.*, p. 297.

[5] Cf. LeClerc, "Macaroni Products," *Cereal Chemistry*, X, 394; J. J. Ager, "A Modern Italian Semolina Mill," *American Miller*, Feb. 1, 1912, XL, 130–31.

[6] LeClerc, "Macaroni Products," *Cereal Chemistry*, X, 395.

[7] *Ibid.*; see also R. P. Skinner, *Manufacture of Semolina and Macaroni* (U.S. Dept. Agr., Bur. Plant Ind. Bull. 20, 1902), p. 20.

[8] Ager, *op. cit.*, p. 131; also personal communications from French millers.

to 40 per cent of semolina. Now that French wheat control makes it so difficult for the French miller to import durum from outside the French empire, he has to depend mainly upon the inferior durums of North Africa, and it is to be presumed that for France as a whole the average yield of semolina is appreciably less than it was when tariffs were the only restriction on importation. However, the French miller is still under greater pressure than his American counterpart to obtain the maximum yield of semolina, because French milling regulations do not permit the clear flour obtained in milling semolina to be used except for feed or export. The result is that much of this flour is exported to Africa. In the United States there are no such restrictions. Here macaroni may be made in whole or in part from flour, though this product may not be sold as "semolina macaroni" but must be sold as "macaroni," unqualified. What conditions obtain today in Italy under the strict control exercised over all branches of the wheat industry we have not ascertained, though durum seems formerly to have been mixed in small proportion with soft wheat flour, in the manufacture of macaroni.

It has not been possible to obtain figures for the United States on the disposition of the flour produced in milling semolina. Much of the better mill streams are sold blended with the poorer quality semolina. There is evidence that at times some has been blended with other flour, but whether this practice is exceptional or common, we have been unable to ascertain.

In Europe the size of the middlings determines the quality. Uniform granulation is important, since the size of the granules influences the rate at which warm water is absorbed when kneading is begun. The coarser granules are considered of higher quality because these tend to be most free from bran particles. It is from these that long macaroni is made because this type of macaroni tends to break where there is a bran particle. The smaller granule sizes are used to make soup pastes, such as alphabets, stars, and other short-cut patterns.[1]

> Much improvement has been made in recent years in the production of high-grade semolina containing very little flour. The results of a special investigation conducted by the Department of Agriculture in 1920 showed that No. 1 semolina contained 0.58% flour, i.e., this amount passed through a 10 XX silk (109 meshes); No. 2, 1.91%; and No. 3, 7.4%. Fully 98% of No. 1 semolina, 82% of No. 2, and 24% of No. 3 remained on 70 XX sieve (68 meshes per inch).[2]

In 1926 B. R. Jacobs of the National Macaroni Manufacturers' Association reported further improvement. "At that time the semolina found on the market had an average flour content of 0.5% (maximum, 1.2; minimum, 0.1)...."[3]

Three sizes of semolina are recognized

> in this country, as well as several special types. No. 1 is the coarsest, No. 3 the finest. In the manufacture of macaroni products, No. 2 is mostly used. . . . The best grade consists of grits of essentially the same size, has a creamy-yellow color, and is practically free from flour and bran.[4]

In general, however, it would seem that in the absence of official grades with government enforcement, grades established by trade usage are not adhered to very strictly. Transactions are very largely based on samples. Purchasers pay much attention to color. While semolina of different color makes macaroni of different color, it is doubtful that finer differences carry through into the finished product. At any rate some semolina millers, especially in Europe, believe that macaroni manufacturers often pay premiums for color in semolina out of all proportion to the effect on the finished product.

In the United States the moisture content of commercial semolina and farina in 1921–26

> ranged from 12.01% to 13.62% and from 12.36% to 13.82%, respectively. In 1927 the new standard of 15% for moisture in flour went into effect .... [and the] moisture content of semolina was 14.04% and of farina 13.92%, which was somewhat higher than that customary before the new standard for flour was adopted.[5]

In the United States high-grade semolina contains: "Moisture, 12%; ash, 0.6%; protein, 11.5%; lipoids, 1.8%; lipoid-phosphoric

[1] LeClerc, "Macaroni Products," *loc. cit.*

[2] *Ibid.*, pp. 395–96.

[3] Zerega, *op. cit.;* cited by LeClerc, "Macaroni Products," *Cereal Chemistry*, X, 396.

[4] LeClerc, *ibid.*, p. 395.

[5] *Ibid.*, pp. 396–97.

acid, 0.048%; water soluble nitrogen, 0.22%; soluble nitrogen precipitable by 40% alcohol, 0.047%."[1] In other countries the composition may be slightly different. It is well known that newly harvested wheat yields flour inferior for baking purposes to that obtainable from the same wheat after it has been stored for some time. Similarly, newly milled flour is inferior for baking purposes to flour aged for two or three months. The changes that occur in wheat or flour when it is stored are quite complex and not wholly understood. One of them is some loss of color. Hence aging does not improve durum wheat for semolina, since color is one of the most important factors in quality. The degree to which pigment is lost in storage varies with the conditions of storage. Under identical conditions wheat loses pigment faster than semolina.[2]

IV. MACARONI MANUFACTURE

The Process

The process of macaroni manufacture has been well covered by LeClerc,[3] and the following discussion of the subject is based largely on his work, unless otherwise noted.

"Before the manufacture of macaroni became an industry, it was made by hand in about the same manner in which it is now made in the home. At first it was sold only in apothecaries' shops, being recommended chiefly for infants and invalids. The first mechanical process for making macaroni was perfected about 1800. . . . .

"The first step in the manufacture of macaroni is the doughing process. For every 100 pounds of semolina or farina some 20 to 30 pounds of water ranging in temperature from 70° to 140° F. are used. The quantity of water varies with the kind of product to be made and the nature of the raw material, less water being used for vermicelli than for macaroni. No other ingredients (except occasionally a small percentage of salt) are used. After being mixed for 10 to 20 minutes, at a temperature of about 40° C. (104° F.), the smooth, firm dough is transferred to a kneading machine or 'gramola'," which operates much like a butter worker.

"The dough is kneaded for 10 to 20 minutes to thoroughly incorporate the water with the semolina or farina and to produce a uniform, smooth, stiff dough.

"When thoroughly kneaded, the dough may be either transferred direct to the press or rolled into sheets, folded into cylinder or cartridge form, and then transferred to the press, which is maintained at a temperature of about 104° F. to keep the dough plastic." In the presses, which may be vertical or horizontal, the dough is forced through a die or perforated plate called *trafila*. The shape of the perforations determines the shape of the product.

The product is then dried or, as it is often termed, "cured." This is a critical step. Soup pastes are dried on trays, but macaroni is cured either "between strawboards (the French system) or on rods (the Italian system)."[4] In the United States, air-conditioned curing rooms or cabinets are mostly used. The drying takes from 36 to 90 hours. If it is too rapid there is surface drying, or case-hardening, causing curling, cracking, and checking. If it is too slow there may be souring and molding. The rate of diffusion of water to the surface layer of the paste is apparently determining. The ideal would be to arrange the rate of evaporation from the surface to equal exactly the rate at which moisture reaches the surface.[5] In modern plants this ideal is approached by drying in carefully air-conditioned rooms[6] instead of in the open or in ventilated chambers.

In the presses, the product is subjected to quite a high pressure—2,500 to 5,000 pounds per square inch. This great pressure and the

[1] LeClerc, "Macaroni Products," *Cereal Chemistry*, X, 391.

[2] Binnington and Geddes, *ibid.*, XIV, 239–44.

[3] "Macaroni Products," *ibid.*, X, 383, 398–411.

[4] Norton, *op. cit.*, p. 932.

[5] D. S. Binnington and W. F. Geddes, "Experimental Drying Equipment for Alimentary Pastes," *Canadian Journal of Research*, February 1934, X, 221–22.

[6] G. G. Hoskins, "Science Dispels Mystery from Macaroni Drying," *Food Industries*, February 1932, IV, 48–51.

subsequent drying apparently have a profound effect upon the structure of the macaroni. The dough, if dried unpressed, would not yield a translucent product.[1]

Types and Standards

In some countries eggs (either whole or yolks only), various comminuted vegetables or juices, and other foodstuffs are added to the dough to produce special types of macaroni. In the United States, under current trade standards, egg macaroni should contain not less than 5.5 per cent of egg solids (moisture-free basis).[2]

The United States Department of Agriculture has promulgated the following definitions for macaroni:

Macaroni. The shaped and dried doughs prepared by adding water to one or more of the following: Semolina, farina, wheat flour. It may contain added salt. In the finished product the moisture content does not exceed 13 percent. Various shapes of macaroni are known under distinguishing names, such as spaghetti, vermicelli.

a. Semolina macaroni is macaroni in the preparation of which semolina is the sole farinaceous ingredient.

b. Farina macaroni is macaroni in the preparation of which farina is the sole farinaceous ingredient.[3]

It costs less to manufacture macaroni from flour than "from semolina, because flour is easier to work and requires less costly machinery."[4] However, there can be no doubt that better macaroni can be made from semolina than from flour, even durum flour. For example, "If the semolina is crushed to a powder it is so separated that what macaroni manufacturers call its 'force' is lost . . . ."[5] There can also be no doubt that durum is superior to bread wheat for macaroni manufacture, for macaroni from bread wheat is duller, less translucent, and somewhat chalky in appearance; it is less elastic; on cooking it is poorer in consistency, i.e., lacks "force"; and its flavor is not so good as that of the durum-wheat product.[6]

In the American trade, there has long been a sharp difference of opinion regarding the propriety of making macaroni from anything other than durum semolina. In consequence, the National Macaroni Manufacturers' Association has suggested definitions for the following types:

Type A. Shall be made from sound semolina No. 2, and the ash content of the finished product, exclusive of added salt, shall not be more than sixty-five hundredths per cent (0.65%).

Type B. Shall be made from sound farina No. 2, and the ash content of the finished product, exclusive of added salt, shall not be more than forty-five hundredths per cent (0.45%).

Type C. Shall be made from a mixture of sound semolina No. 2 and sound farina No. 2, and the ash content, exclusive of added salt, shall not be more than fifty-five hundredths per cent (0.55%).

Type D. Shall be made from sound hard wheat flour or sound durum wheat flour of a grade not lower than ninety-five per cent (95%) patent, and the ash content, exclusive of added salt, shall not be more than fifty-two hundredths per cent (0.52%) when a hard wheat flour is used, and shall not be more than sixty-five hundredths per cent (0.65%) when durum wheat flour is used.

Shall contain not more 12% moisture, as determined by the vacuum oven method or other method which the Association of Official Agricultural Chemists may consider as equivalent, and not less than 11% of protein ($N \times 5.7$) calculated on 12% moisture basis.[7]

The purpose of setting an upper limit for ash is to prevent the use of products of lower quality than 95 per cent patent flour. On the contrary, if the ash content is lower than 0.50 per cent, the macaroni is probably not a durum or hard-wheat product. Soft wheats produce very inferior products and are rarely used, for such macaroni becomes soft and sticky when boiled. It is said, however, that in some parts of Europe a small amount of macaroni is made from soft wheats for use in such dishes

[1] Fifield, Smith, and Hayes, *op. cit.*, pp. 670–72.

[2] *Trade Practice Rules for the Macaroni, Noodles and Related Products Industry as Promulgated July 7th, 1938 by the Federal Trade Commission, Washington, D.C.* Reprint by National Macaroni Manufacturers' Association, Braidwood, Ill., [n.d.], p. 4.

[3] *Definitions and Standards for Food Products for Use in Enforcing the Food and Drug Act*, p. 8.

[4] LeClerc, "Macaroni Products," *Cereal Chemistry*, X, 8.

[5] Norton, *op. cit.*, p. 931.

[6] *Ibid.*, pp. 932–33.

[7] LeClerc, *Cereal Chemistry*, X, 411–12.

as macaroni *au gratin* in which softness and stickiness of the macaroni is not apparent.

In the United States macaroni is required to be free from artificial coloring.

Good macaroni should be hard, brittle, and elastic. Binnington, Johannson, and Geddes[1] have devised an apparatus for measuring the transverse breaking strength of macaroni. The factors contributing to breaking strength seem to be complex. Among them are granulation, protein content, and protein character of wheat. High protein content tends to increase breaking strength. Macaroni made from semolina has a lower breaking strength than that made from patent flour from the same wheat. the macaronis made experimentally by Binnington, Johannson, and Geddes all had a considerably lower breaking strength than those made commercially.

Good macaroni should be translucent and have a high amber color; that with the greatest proportion of yellow is usually preferred. It should be pliable, and long macaroni should bend considerably. Its surface should be more or less rough instead of smooth, and there may be a few bran specks. "It should break with a clean glassy fracture."[2] The fracture surface tends to be whiter at the periphery than in the interior, probably due to friction with the die in the press. Held up to the light, it should not appear homogeneously translucent but should show some irregularity reminiscent of the semolina or farina from which it was made. There should be no hair-like cracks, which are due to faulty drying. On chewing there should be no acid taste.

"Macaroni of inferior quality has a dull color, often gray. If made from bleached flour it will be white. It will break unevenly and with ragged edges."[3]

"The real test of a macaroni is its behavior on boiling. When boiled for 10 minutes, a good macaroni will swell to at least twice its original size, will retain its tubular shape and its firmness, will not become pasty, and will have an agreeable odor."[4]

Borasio[5] has designed an apparatus for cooking macaroni under constant conditions. He has determined that better qualities gain more in weight than poor ones when cooked. He has also developed a volumometer to determine gain in volume, which is greatest for the highest qualities. The degree to which the macaroni is dispersed in cooking may be judged by the turbidity of the water in which it has been cooked. The amount of sediment that settles out is significant in this regard and is most abundant in goods of low quality. Exact measurement of dispersion is made by determining total solids and correcting for common salt. In general, solids in the cooking water do not exceed 6 per cent of the weight of good-quality macaroni.

Since Borasio did not develop a method for determining the exact point when the macaroni is cooked, Binnington, Johannson, and Geddes[6] employed an instrument for this purpose resembling that used by Bonney, Clifford, and Lepper[7] for fruits and vegetables. They found that there is a definite time of cooking beyond which excessive softening develops. They also improved Borasio's technique in various other ways.

Wheat Quality for Macaroni

Samples of durum wheat vary greatly in their suitability for making macaroni due both to variety and to the conditions under which the grain was grown. Long experience by the macaroni manufacturers has resulted in the practice of offering premiums for high quality amber durum varieties, such as Mindum and Kubanka, while low quality varieties such as Pentad (red durum), Monad, and Acme, grown in the same locality, bring a low price.[8]

Amber durum is most suitable for the production of semolina, as it combines strength with a most desirable creamy-yellow color. Red durum should not be, and generally is not, used for making semolina, as macaroni made from it has a dull-gray color. Although the amount of amber durum produced in this country fit for making

[1] D. S. Binnington, H. Johannson, and W. F. Geddes, "Quantitative Methods for Evaluating the Quality of Macaroni Products," *Cereal Chemistry*, March 1939, XVI, 149–67.

[2] LeClerc, "Macaroni Products," *Cereal Chemistry*, X, 412. [3] *Ibid.* [4] *Ibid.*

[5] L. Borasio, "Das Kochen der Teigwaren (Maccaroni)," *Das Mühlenlaborium*, August 1936, VI, 114–15.

[6] *Loc. cit.*

[7] V. B. Bonney, P. A. Clifford, and H. A. Lepper, *An Apparatus for Determining the Tenderness of Certain Canned Fruits and Vegetables* (U.S. Dept. Agr. Circ. 164, April 1931).

[8] Fifield, Smith, and Hayes, *op. cit.*, pp. 661–62.

high-grade semolina is relatively small, it is, as a rule, sufficient to meet the needs of the semolina millers.[1]

Inspection alone is inadequate to appraise quality, although it is still the major method of examination. There is, to be sure, a large degree of correlation between the appearance of the kernels and the quality of the macaroni that may be produced from them, but appearance is not infrequently deceptive. For example, poor color of the bran coat sometimes masks good quality even in amber varieties.[2]

Estimation of the protein content is a widely used and valuable criterion but it furnishes no information regarding the other important criterion, color. Indeed, there is sometimes a tendency for decreasing protein content to be associated with increasing carotin content. "Lowered protein content affects colour adversely by reducing the vitreousness and translucency," which may be "offset to a considerable extent by the increased carotene content."[3]

Hence estimation of the gasoline-color value is much used. This is merely the examination of the color of a gasoline extract of semolina. Unfortunately this test fails occasionally, because some samples "may be high in yellow coloring matter and bleach out pale when processed into macaroni."[4] Despite its occasional failure, the gasoline test is of considerable value, for in most varieties there is a high degree of correlation between gasoline color and macaroni quality.[5]

Unlike protein content, gasoline color seems little influenced by locality. The factors which influence yield, however, seem also to influence color. Clark[6] has suggested that:

> The negative correlation between weight and color may be due to carotin pigment being deposited during the early stages of development of the kernel. Damage from rust or drought which would prevent normal development of the kernel would then result in a higher proportion of carotin in light weight wheat. Durum wheat of low grade, due to low test weight per bushel, therefore appears to have a greater chance of being better in color than wheat in grades of high test weight per bushel.

According to Clark, there is a negative correlation between yellow color and high crude-protein content. This is unfortunate.

> The semolina industry desires durum wheat which will make macaroni of a yellowish color and at the same time be hard and vitreous and retain its form after cooking. It is thought that durum wheats producing a hard vitreous product should have a high crude protein content. As there is an important correlation between low content of crude protein and yellow color a median position for both factors must be a necessary object of improvement, with color having the preference.[7]

This negative correlation between protein content and yellow color is apparently not peculiar to durum but is also found in hard spring wheats. Like durums the latter tend to be low in protein and abnormally yellow in color in wet seasons or in humid climates, the whole or only part of the berry being affected so that its appearance is mottled. At one time much research in the United States was aimed at the discovery of ways and means to remedy this condition, popularly called "yellow-berry." Indeed, chemical bleaching was first employed to improve the color of flour from such yellow-berry wheat. There is an extensive literature on the subject.[8]

Another test that has been suggested is the estimation of carotin, the yellow pigment. However, semolina contains less carotin than the wheat from which it is milled,[9] and there is reason to believe that the relation between wheat carotin and semolina carotin is very irregular.[10] When thin, rusted, and immature

[1] LeClerc, "Macaroni Products," *Cereal Chemistry*, X, 389, 392.

[2] Fifield, Smith, and Hayes, *op. cit.*, p. 663.

[3] W. F. Geddes and D. S. Binnington, *Quality Characteristics of the 1937 Canadian Amber Durum Wheat Crop* (Canada, Board of Grain Commissioners, Grain Research Laboratory, Winnipeg, mimeographed, Oct. 16, 1937), p. 6.

[4] Fifield, Smith, and Hayes, *op. cit.*, p. 664.

[5] Clark, "Improving Quality of American Grown Durum Wheat," *Macaroni Journal*, VI, 22.

[6] *Ibid.*, p. 23. [7] *Ibid.*

[8] See C. L. Alsberg and E. P. Griffing, "Environment, Heredity, and Wheat Quality," WHEAT STUDIES, March 1934, X, 234, 243–44, 245.

[9] Binnington and Geddes, "The Relative Loss in Pigment Content of Durum Wheat, Semolina and Spaghetti Stored under Various Conditions," *Cereal Chemistry*, XIV, 240–42.

[10] D. S. Binnington and W. F. Geddes, "The Relative Macaroni Making Quality of a Number of Durum Wheat Varieties," *ibid.*, May 1937, XIV, 293–304, especially p. 298.

kernels are present, the pigment content is high, for these types of kernel may contain two or more times as much as normal kernels.[1] Indeed, Binnington and Geddes[2] present evidence that little, if any, relation exists between carotinoid content of durum wheat and the color of macaroni produced therefrom. This idea is in harmony with their observations that the carotin content of spaghetti is only a fraction of that of the semolina from which it is made.[3] It is also in harmony with the observations of Fifield, Smith, and Hayes[4] that the bright color of macaroni made from the varieties, Mindum and Kubanka-75, grown in North America, is not wholly paralleled by the quantity of carotin content estimated chemically.

This lack of close correlation between carotin content of wheat and color of semolina is not astonishing if one realizes that it is the resultant of at least five variables. As Vogel and Bailey[5] put it:

> These are (1) content of carotinoid pigments, (2) relative density, or vitreousness, of the particles, (3) size of the particles, (4) pigments contributed by the outer fibrous covering, or bran, of the kernel, and (5) dirt or foreign material. A sixth factor becomes operative when the semolinas are wetted, namely, the production of dark substances or pigments in consequence of oxidation accelerated by enzymes known as oxidases.

A simple method widely practiced is to wet and dry slicks of semolina, which requires much experience. Moreover, "the best looking semolina does not always produce the best macaroni."[6] Indeed, it is the private opinion of some semolina millers that the color of the semolina does not necessarily carry over completely into the finished paste and that paste manufacturers are often accustomed to pay unwarranted premiums for color in semolina.

Experimental Macaroni Making

As in determining the baking quality of a flour, the only definitive test as yet devised is to bake bread, so it would seem that the only definitive test of semolina quality is to make macaroni. Within the last few years Binnington and Geddes[7] in Canada and Fifield, Smith, and Hayes[8] in the United States have devised apparatus and techniques for milling small samples of durum wheat and making macaroni from them. Binnington and Geddes[9] have devised apparatus for drying under known and exactly controlled conditions, using a specially designed automatic recording balance to observe the course of drying.[10] The studies of these Canadian and American investigators seem to be the first strictly quantitative researches into the effect of varying the steps of the manufacturing process upon the properties of the resulting macaroni.

Among the observations made are the following: The length of the tempering time of the wheat and the milling procedure affect the pigment content of the semolina and hence of the finished macaroni. Variations in carotin are associated with the presence of varying quantities of germ. Amount of absorption also affects color. So does the time of kneading, the length of the rest period between kneading and pressing, and the temperature of pressing. The pressure in the press is the outstanding factor in bringing out the clear, bright color desired. The bright color of vitreous wheat is lost when it is tempered, and does not reappear at any stage of the process until pressure is applied in the final step in the macaroni press.

Fifield, Smith, and Hayes[11] used a pressure of 8,000 pounds per square inch, whereas in commercial practice pressure ranges from 2,500 to 5,000 pounds are employed.[12] Their products were brighter than those made commercially with the lower pressures, and they

[1] Binnington and Geddes, "The Relative Macaroni Making Quality of a Number of Durum Wheat Varieties," *Cereal Chemistry*, XIV, 298. [2] *Ibid.*, p. 303.

[3] "The Relative Loss in Pigment Content of Durum Wheat, Semolina and Spaghetti Stored under Various Conditions," *ibid.*, p. 240.

[4] *Op. cit.*, p. 664. [5] *Op. cit.*, pp. 143–44.

[6] Fifield, Smith, and Hayes, *op. cit.*, p. 663.

[7] D. S. Binnington and W. F. Geddes, "Experimental Durum Milling and Macaroni Making Technique," *Cereal Chemistry*, September 1936, XIII, 497–521.

[8] *Op. cit.;* C. C. Fifield, "Experimental Equipment for the Manufacture of Alimentary Pastes," *Cereal Chemistry*, May 1934, XI, 330–34.

[9] "Experimental Drying Equipment for Alimentary Pastes," *Canadian Journal of Research*, X, 221–33.

[10] D. S. Binnington and W. F. Geddes, "An Automatic Recording Balance," *Industrial and Engineering Chemistry, Analytical Edition*, Jan. 15, 1936, VIII, 76–79. [11] *Op. cit.*, pp. 669, 671–72.

[12] LeClerc, "Macaroni Products," *Cereal Chemistry*, X, 404.

suggest that the industry might perhaps use to advantage pressures higher than is customary. They also suggest that some shapes might be made to advantage by stamping out under high pressure rather than forcing through a die. The use of high pressure, moreover, probably renders the product less sensitive to changes during drying. B. R. Jacobs[1] has suggested that one gets a deeper layer to look into; brightness is enhanced by greater pressure because the product is more compact and has something of the characteristics of vitreous wheat.

Fifield, Smith, and Hayes[2] also showed that the unpressed material loses moisture more rapidly than the pressed product. Moreover, after passing through the press the product turns brown, i.e., caramelizes, when heated to 130° C. whereas the unpressed product remains white. They suggest that the starch granules have been broken up by pressure and that the starch is hydrolyzed, at least partially, perhaps to dextrin. Such hydrolysis would explain the slower water loss in the pressed product. They propose to undertake chemical study of these phenomena. The questions raised need also to be studied with the microscope to determine to what degree the granules have been ruptured. It is not improbable that merely soluble starch from ruptured granules is formed, rather than dextrin. Such starch, being colloidally dispersed, would tend to retain water more tenaciously than uninjured starch granules. Moreover, there might result increased and continuing diastase action with the formation of much maltose which, as is well known, caramelizes very easily. All these are problems for future study.

Whatever the effect upon the starch of pressure during manufacture, neither the starch nor the protein is more digestible than in bread. Woods and Snyder[3] found the coefficients of digestibility of starch to be 97.4 in macaroni and 98.0 in white bread, and for protein 86.8 and 88.0 respectively.

Perhaps the modification of the starch under pressure explains why cooked pastes do not seem to grow stale. Alimentary pastes do not undergo the change that takes place in bread when it grows stale, for it has been found at the Food Research Institute that the Katz[4] test, which shows up staleness in bread crumb, fails to show the development of an analogous state in pastes. It has been demonstrated that breaking up or comminuting starch granules, for example by long-continued grinding, destroys or greatly lessens their power to form starch paste. If this is the state of the starch in macaroni, it would be in a condition different from that in bread —especially if much of the starch has become soluble. Moreover, macaroni is boiled in an excess of water, whereas in bread the granules are heated in the oven in the presence of insufficient water to gelatinize them completely. Apparently the behavior of starch granules in cookery is greatly influenced—how is not known—by the relation of the granules to the matrix in which they are imbedded, for boiled potatoes like boiled macaroni do not grow stale,[5] as judged by the Katz test.[6] Perhaps it is the effect of pressure upon this granule-matrix relationship that accounts for the absence of staleness.

It is well known that spaghetti when canned, as it is in the United States, may be stored for many months on grocers' shelves before it is consumed. Yet complaints that such ready-prepared dishes grow stale are unknown to canners. This is not, however, to be taken as evidence that under other conditions staleness would not occur. Everyone knows that stale bread, if it has not dried out too much, may be freshened by heating. Canned spaghetti cannot, of course, dry out, and it is commonly heated for the table.

Uncooked macaroni changes very little. It shows no significant decrease in pigment content even after a year's storage.[7] If stored too

[1] Personal communication. [2] *Op. cit.*, p. 671.

[3] C. D. Woods and H. Snyder, *Cereal Breakfast Foods* (U.S. Dept. Agr. Farmers' Bull. 249, 1906), p. 18.

[4] J. R. Katz, *Het Oudbakken Worden van het Brood in Verband met het Vraagstuk van den Nachtarbeid der Bakkers* (Dissertation, Amsterdam, 1917; 's-Gravenhage, 1917).

[5] Unpublished observations of E. P. Griffing, made at the Food Research Institute.

[6] Whether this test is a true measure of staleness remains to be shown. Cf. Alsberg, "The Stale-Bread Problem," WHEAT STUDIES, XII, 221–47.

[7] Binnington and Geddes, "The Relative Loss in Pigment Content of Durum Wheat, Semolina and Spaghetti Stored under Various Conditions," *Cereal Chemistry*, XIV, 243.

long, it may dry out, become more brittle, and even check; but this seems to be of no practical importance. Skinner,[1] however, states that old alimentary pastes are less palatable than recently manufactured ones.

The fact that macaroni and other pastes are boiled and not baked in an oven gives them an advantage where fuel is expensive, for boiling in general requires less fuel than baking. The necessary equipment also is cheaper. Therefore, the preparation of pastes for the table is cheaper, simpler, and requires less skill than the baking of bread. On the other hand, pastes are not palatable unless they are consumed warm, while cold bread is palatable until it becomes quite stale. Pastes, unlike bread, cannot be cooked and held for a number of days before they are eaten. Therefore, cooking of pastes for each meal is time-consuming and inconvenient. Several days' supply of bread, on the other hand, can be made at a single baking. Cooked pastes are not conveniently portable. They are not suitable for an army on the march which hasn't time to stop and boil macaroni for each meal. However, it is worth noting that macaroni and related products, if made from vitreous durum, tend to contain proportionally much more protein than bread. This may be a factor favoring consumption in countries where meat consumption is small, especially where the paste is reinforced by cooking or eating it with cheese, as is a common Italian custom. However, since macaroni is unfermented, it lacks the nutritive constituents furnished by yeast, of which vitamin B is the most important.

[1] *Manufacture of Semolina and Macaroni*, p. 27.

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