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Nutritional Improvement of Wheat by Breeding*

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An estimated one billion people or 35 per cent of the world's population rely upon wheat as their principal food. The wide adaptation of wheat as reflected in its productivity in an array of environments and the desirability of its grain as human food suggest that the role of wheat as a major food crop of the world will continue. Thus, its nutritional adequacy is of basic importance.

Substantial enhancement of nutritional value would accrue from an increase in the quantity of protein in wheat. Increases in protein quantity can be accomplished with applications of nitrogen fertilizer in some production areas but has serious limitations in other areas. Improved levels of grain protein probably will require a combination of fertilizer application and the use of varieties with the capacity to synthesize more protein in their grain than currently grown varieties.

The protein of wheat lacks the necessary balance of amino acids essential for tissue synthesis and body growth. This is true also of rice, maize, and the other cereal grains. Lysine, methionine, and threonine, probably in that order, are the most deficient of the amino acids in wheat protein. Increases in the level of each, particularly lysine, would provide better amino acid balance and enhanced nutritional value.

Neither the quantity of protein nor its nutritional value has been subjected to serious improvement efforts by wheat breeders until recently. The strong influence of environment on the protein level and the problems of genetic manipulation of protein and its amino acid content discouraged serious breeding efforts.

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PROTEIN QUANTITY

The influence of environment on level of protein in wheat is large. The protein content of a hard wheat variety may vary from 8 to 18 per cent, depending on the environment. "High protein" does not imply a "fixed" high level—rather a higher level than other varieties grown in the same environment.

The identification of the soft winter variety, "Atlas 66", in the United States as a high protein wheat demonstrated that significant increases in protein level are possible through breeding (MIDDLETON, BODE and BAYLES, 1954). Atlas 66 and a sister variety, "Atlas 50", are derivatives of the South American variety, "Frondoso". They have been extensively utilized in some of the breeding programmes in the United States. Cooperative investigations of high protein in wheat by the Agricultural Research Service, USDA, and the Nebraska Agricultural Experiment Station since 1954 have further elucidated genetic and physiological aspects of the high protein phenomenon.

A gene for high protein from Atlas 66 is closely associated with leaf rust resistance (JOHNSON, SCHMIDT and MATTERN, 1968). High protein selections from crosses of Atlas 66 with "Comanche" and "Wichita" hard winter wheats were predominantly resistant to leaf rust in the adult stage. This association and the relative ease with which high protein lines could be selected suggest a relatively low number of major genes for high protein (HAUNOLD, JOHNSON and SCHMIDT, 1962). Heritability estimates for protein as high as 0.82 indicate that effective breeding progress for the trait can be made (STUBER, JOHNSON and SCHMIDT, 1962). The high protein of Atlas 66 has been transferred to other wheats. Experimental lines of hard red winter wheat with 2 to 4 per cent more actual protein in their grain than currently grown varieties have been selected at the Nebraska Station (JOHNSON *et al.*, 1963). In several years of testing in Nebraska, the lines have been equal to or more productive than their hard wheat parents. Thus, the increase in grain protein was achieved without reductions in yield. The trait appears to be relatively stable under conditions in the winter wheat producing area of the United States. Whether comparable expression of the high protein trait can be achieved in other wheat-producing areas of the world is not known.

High grain protein in wheat is not believed to depend upon differential nitrogen uptake by the wheat plant. We have been unable to demonstrate the level of nitrogen in the vegetative tissues of wheat to be related to differences in protein content of the grain (JOHNSON, MATTERN and SCHMIDT, 1967). Significant varietal differences in the nitrogen content of the vegetative tissues were detected but were unrelated to the level of protein in the grain. The lines derived from Atlas 66 were higher in protein content of their grain at all stages of kernel development and maturation. We believe that the high grain protein was the result of more efficient and more complete translocation of nitrogen from the plant to its grain. Therefore, the high protein trait should be expressed in an array of environments.

NUTRITIONAL QUALITY OF THE PROTEIN

We have assayed the amino acid content of several of the lines derived from Atlas 66. The lysine, methionine, and threonine content of a few of the lines are compared with the parent varieties in Table 1. Lysine was not depressed in the lines shown and, in some, the level of lysine was somewhat higher than in either parent variety. All but one of the lines were comparable to Comanche in methionine, but several were lower than either parent in threonine. It appears that the high protein of the Atlas 66-derived lines need not be associated with depression of either lysine or methionine.

TABLE 1. Lysine, methionine, and threonine levels in selected high protein lines of Atlas 66 x Comanche.

Variety	Protein content[1]	Lysine % protein	Methionine % protein	Threonine % protein
Comanche	15.0	3.23	1.67	3.54
Atlas 66	18.0	3.33	1.11	3.35
Atlas 66—Cmn 2509	18.3	3.45	1.83	3.32
" 2500	18.3	3.20	1.65	3.16
" 2499	18.2	3.29	1.68	3.10
" 2504	17.9	3.38	1.14	3.69
" 2507	17.7	3.72	1.74	2.62
" 2510	16.5	3.37	1.67	3.22

[1] Dry weight basis.

The Nebraska Agricultural Experiment Station in cooperation with the Agricultural Research Service, USDA, is engaged in research on the nutritional improvement of wheat protein. The work is supported in part by funds from the Agency for International Development, U.S. Department of State. The common and durum wheats in the World Collection maintained by the U.S. Department of Agriculture are being systematically analyzed to identify new genetic sources of high protein and high lysine. To date 4,100 varieties of the common wheats have been analyzed. Protein content ranged from less than 9 to over 21 per cent with a mean of 13.5% (dry weight basis). Lysine expressed as per cent of protein ranged from 1.77 to 4.15% with a mean value of 3.03%. More than one-half the samples possessed lysine in the range of 2.9 to 3.2 per cent. The lysine content of 80 samples exceeded 3.5 per cent and five were above 3.8 per cent.

The relationship of protein and lysine (expressed as per cent of protein) is negative. However, the effect of protein level on lysine/protein is relatively modest. The regression of lysine (per cent of protein) on protein and the dispersal of actual lysine values about the regression line are shown in Figure 1. Only 18 per cent of the variation in lysine content is attributable to variation in protein.

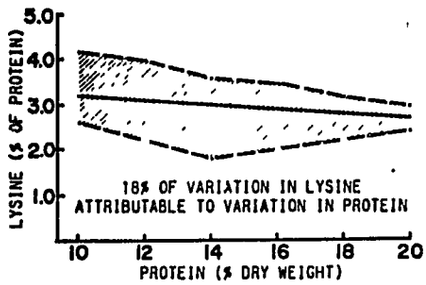

FIG. 1. Regression of lysine (% of protein) on protein and the range of dispersal of lysine values about the regression line computed from the analyses of 4,100 common wheats from the World Collection.

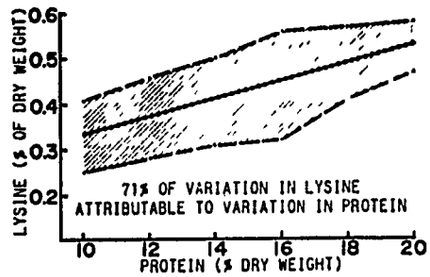

FIG. 2. Regression of lysine (% of dry weight) on protein and the range of dispersal of lysine values about the regression line computed from the analyses of 4,100 common wheats from the World Collection.

The regression of lysine (per cent dry weight) on protein is shown in Figure 2. The relationship is strongly positive, as would be expected, because lysine is a constituent of protein. Seventy-one per cent of the variation in lysine (dry weight basis) can be attributed to variation in protein. For this reason we prefer lysine values expressed as a per cent of protein for screening and selection purposes since they are less affected by differences in protein.

The 10 varieties with the highest lysine/protein content among 4,100 samples are identified in Table 2. Seven are from the United States and eight have the winter habit of growth. They are arranged according to their adjusted lysine/protein values. The regression coefficient was utilized to adjust values

TABLE 2. Protein and lysine content of selected high lysine wheats from the World Collection.

C.I. No.	Origin	Growth habit	Protein content[1]	Lysine (% of protein)	
				Unadjusted	Adjusted[2]
13449	U.S.A.	Winter	9.2	4.15	3.91
11721	Canada	Spring	10.2	4.08	3.89
11696	U.S.A.	Winter	11.1	3.97	3.83
13447	U.S.A.	Winter	10.3	3.87	3.69
9364	Finland	Winter	11.4	3.76	3.64
9390	China	Winter	10.0	3.83	3.64
12369	U.S.A.	Winter	16.2	3.47	3.61
1970	U.S.A.	Winter	12.5	3.65	3.59
11723	U.S.A.	Spring	10.1	3.77	3.58
11743	U.S.A.	Winter	10.4	3.76	3.58
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5483	Russia	Spring	14.3	1.77	1.81

[1] Dry weight basis.
[2] Values adjusted to 13.5% protein.

to a 13.5% protein level. We believe that such an adjustment is valid and can be useful for identification of genetically high lysine varieties and the screening of populations segregating for lysine level.

How useful these wheats will be for breeding purposes will depend largely on the stability of the high lysine trait. Limited data from nurseries at three different sites in the United States indicate significant genotype-environment interactions for lysine content (JOHNSON *et al.*, 1968). The lysine content of some lines varied substantially less than other lines. One line from the World Collection, C.I. 7337, had a significantly higher lysine/protein content than 37 of the 40 varieties tested.

INTERNATIONAL WINTER WHEAT PERFORMANCE NURSERY

An International Winter Wheat Performance Nursery is being established by the Nebraska Agricultural Experiment Station in 1968 with informal cooperation of the Agricultural Research Service, USDA, and the International Maize and Wheat Improvement Center, Mexico. The effort is supported in part by funds from the Agency for International Development, U.S. Department of State. The nursery is similar to the International Spring Wheat Yield Nursery established several years ago by the Rockefeller Foundation in Mexico. Initially, it will be comprised of 30 winter wheat varieties of diverse breeding background from various countries of the world. We anticipate that the nursery will be grown at as many as 20 sites in 14 or 15 countries.

The nursery will permit early identification of superior winter wheat varieties having broad adaptation for use as recipient genotypes for high protein and high lysine genes. It will be an effective vehicle for assessing the stability and degree of expression of the high lysine and high protein traits in diverse environments. We believe that it can also serve for wide scale and rapid testing of new materials with improved nutritional quality as they are developed.

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