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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

IMPROVEMENT OF WHEAT QUALITY IN RELATION TO
BREEDING METHODOLOGY : PROTEIN QUALITY

by

V.A. Johnson and P.J. Mattern

The nutritional value of cereal grain is mainly a function of the amount of protein it possesses, the biological availability of the protein, and the amino acid composition of the protein. The level of protein in wheat is high in relation to the other major food cereals, rice and maize. Wheat averages approximately 12% protein compared to only 10% for maize and 8% for rice.

The amino acid composition of wheat protein is not as balanced as that of rice but is better balanced than the protein of ordinary maize. An explanation can be found in the protein solubility fractions of the three cereals. Nearly 90% of rice protein is comprised of alkali soluble glutelins making it unique among the cereals. Glutelin protein is characteristically high in lysine. In contrast, wheat and maize protein possess only 30-40% glutelin and approximately 50% of the lysine-poor prolamin fraction.

Biological availability of their protein probably is comparable in wheat, rice, and maize, and generally better than that of sorghum protein. The frequently low biological availability of sorghum protein is believed to be associated with tannins in the grain that alter the protein solubility by binding and forming complexes with the protein (1). This problem is not known to exist in rice, wheat, or maize.

The approach to nutritional improvement by genetic means is dictated mainly by the particular protein deficiencies of the cereals species and by the existing or inducible genetic variation for the trait to be manipulated. Useable genetic variation for level of protein in the grain of wheat was identified before 1960 (7). Additional genetic sources have been detected (4).

Nutritional value of wheat protein is limited by a short supply of the essential amino acid lysine. Ordinary wheat protein has only one-half the amount of lysine required to satisfy the minimal requirements of adult man (Table 1). Isoleucine, methionine, and threonine also are in short supply in wheat protein, but less so than lysine. We believe that a 25% increase in lysine is required for it to be in reasonable balance with other essential amino acids.

We have systematically analyzed for protein and lysine 12,600 common wheats (*Triticum aestivum* L.) in the World Wheat Collection maintained by the Agricultural Research Service, U.S. Department of Agriculture. Total protein variation ranged from 7 to 22%. We have determined that a large part of this variation is non-genetic. Our data suggest that the genetic component of total protein variation probably does not exceed 5 percentage points.

Lysine variation among wheats in the World Collection was from 2.2 to 4.2 percent when lysine is expressed as percentage of total protein. Again, we have detected strong influence of environment on level of lysine and have been able to demonstrate only 0.5 percentage point as the measurable genetic component of total lysine variation. This is less than one-half the amount of increase in lysine needed to bring it into acceptable balance with other essential amino acid.

TABLE 1

DEVIATION OF ESSENTIAL AMINO ACIDS (EXCEPT TRYPTOPHAN) IN
WHEAT FROM REQUIREMENTS OF MAN, FAO-1957

Amino acid	Deviation from requirement %
Lysine	- 55.0
Methionine ¹	- 12.5
Isoleucine	- 16.7
Leucine	+ 30.4
Tyrosine	+ 9.7
Phenylalanine	+ 40.4
Threonine	- 3.4
Valine	+ 4.5

¹ Adjusted provisional amino acid pattern (WHO, 1965).

Most of the nutritional research activities in maize have been centered about improved amino acid balance induced by the opaque-2 and floury-2 genes (6, 9). Significant progress has been reported (3, 7). There has been little progress in significantly increasing the protein level of maize without sacrifice of yield. A high protein exotic South American maize species recently was shown to produce a multiple layer of aleurone cells instead of the typical single layer (10). This may prove to be useful for effectively increasing the protein content of maize by breeding.

Research efforts to date in rice have been directed toward increasing its protein content. Encouraging results have been reported from the International Rice Research Institute (2).

This meeting is concerned with the productivity of wheat. Although my research has dealt mainly with wheat protein, I subscribe to improved productivity as the logical foundation for all wheat improvement efforts. There is a serious calorie problem in the world as well as a protein problem. The two are not separate problems. It is difficult or impossible to achieve protein adequacy in the diet of a malnourished person because the protein will be converted in part or entirely to calories until the person's minimal requirement for calories has been satisfied.

I reported to this group at its meeting in Ankara in 1970 on the research findings from the cooperative Agricultural Research Service - Nebraska Agricultural Experiment Station project to improve the nutritional quality of wheat by breeding. Last year I again reported our results at an International Winter Wheat Conference held in Ankara, Turkey. This information has been published (4, 5). My discussion, therefore, will be confined mainly to recent new research findings and their implications for nutritional improvement of wheat.

Lysine per unit of protein is negatively correlated with protein in the grain of wheat. Our analyses of the World Wheat Collection reveals that the relationship is curvilinear. It is pronounced at low levels of protein but disappears at levels

above 15% protein. We have fit the curve to a mathematical equation which we now utilize routinely to adjust all of our lysine data to a single protein level to permit valid comparisons of lysine values.

Among 12,651 wheats in the World Collection, CI13449 possessed the highest adjusted lysine value of 3.72%. Nap Hal (PI176217) initially identified in Montana for higher-than-normal protein content, also has produced above-normal lysine content in our trials. Its lysine value in the World Collection was above normal but not as high as several other wheats.

We crossed Nap Hal with Atlas 66. We have analyzed F_2 progeny bulks in the F_3 and F_4 generations from this cross. The F_3 protein frequency distribution indicated an apparent transgressive segregation for level of protein among the F_2 progeny bulk rows. We interpret this as evidence of different genes for high protein in the parent varieties Atlas 66 and Nap Hal.

The protein frequency distribution for the Nap Hal x Atlas 66 F_2 progeny bulks in the F_4 generation is similar to the F_3 distribution. Again, there is strong indication of transgressive segregation for both high and low protein.

The frequency distribution for lysine among the F_2 progeny bulk rows from the Atlas 66 x Nap Hal cross in the F_3 generation showed no evidence of transgressive segregation for lysine. Our data indicated that the Nap Hal level of lysine has apparently been recovered in F_3 rows that also possess very high protein content.

Correlations of F_3 protein and lysine values with F_4 values were highly significant statistically but not high. Varying degrees of seed plumpness probably was the major contributing factor.

When Nap Hal was crossed with CI13449, F_2 bulk progeny rows grown in the F_3 generation produced the protein frequency distribution of the type where there was recovery of parental levels of protein among the progeny but none exceeded the Nap Hal parent. An F_3 population mean for protein only slightly higher than that of CI13449 suggests partial dominance of low protein in the cross.

In the F_3 frequency distribution for adjusted lysine per unit protein in the Nap Hal x CI13449 cross the Nap Hal and CI13449 parents produced lysine levels of approximately 3.2 and 3.4% respectively compared to less than 3.0% for the Triumph 64 and Atlas 66 check varieties. Lysine values among the F_3 rows ranged from 2.8 to 4.0% with a substantial number exceeding the level of both parents. The evident transgressive segregation suggests the opportunity to select lysine levels significantly higher than the parents among the progeny of this cross. The levels among the progeny rows are among the highest we have obtained from experimental materials since initiation of the research in 1966.

A small animal bioassay laboratory in which the mouse is utilized as the test animal was established at the Nebraska Agricultural Experiment Station in 1971 as a part of our AID-supported wheat nutritional improvement effort. Wheat with unusual protein and amino acid values based on in-vitro laboratory analyses are being subjected to mouse feeding trials.

In 1972, several high protein Atlas 66-derived experimental lines were fed. Results are summarized in Table 2. Mice fed wheats that averaged 17.5% protein made weight gains that were substantially higher than gains from lower protein wheats. The most promising segregates from the Nap Hal x Atlas 66 and Nap Hal x CI13449 crosses will be subjected to mouse bioassays in 1973 and 1974.

These data are the basis for optimism on our part that we can effectively improve the nutritional value of wheat. We believe that this can be accomplished in highly productive, agronomically acceptable wheat varieties.

TABLE 2

MEAN MOUSE WEIGHT GAINS AND FEED EFFICIENCY RATIOS FROM WHEAT SAMPLES DIFFERING IN PROTEIN CONTENT FED TO WEANLING MICE FOR A 28-DAY PERIOD (5 MICE PER SAMPLE).*

No. of samples	Protein content	Mean protein	Mean weight gain	Mean feed efficiency ratio ¹
	%	%	g	
14	17.0-18.6	17.5	15.1	8.6
16	15.1-16.8	16.1	12.9	9.4
14	13.5-14.8	14.3	13.5	9.3
5	10.8-12.9	11.7	10.2	11.1

¹ Feed consumption + weight gain

* Taken from Johnson and Lay. J. Agr. Food Chem. (in press)

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