AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

# BIBLIOGRAPHIC INPUT SHEET

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1. SUBJECT CLASSIFICATION

A. PRIMARY: Agriculture — AF30-0180-0000

B. SECONDARY: Plant breeding--Cereals--Wheat

2. TITLE AND SUBTITLE

Protein improvement in wheat

3. AUTHOR(S)

Johnson,V.A.; Schmidt,J.W.; Mattern,P.J.

| 4. DOCUMENT DATE | 5. NUMBER OF PAGES | 6. ARC NUMBER |
|---|---|---|
| 1970 | 8p. | ARC 633.11.J69j |

7. REFERENCE ORGANIZATION NAME AND ADDRESS

Neb.

8. SUPPLEMENTARY NOTES (*Sponsoring Organization, Publishers, Availability*)

(In Proc.,3d FAO/Rockefeller Found.Wheat Sem.,Ankara,p.166-172)

9. ABSTRACT

10. CONTROL NUMBER

PN-RAA- 254

11. PRICE OF DOCUMENT

12. DESCRIPTORS

Amino acids
Proteins
Wheat

13. PROJECT NUMBER

14. CONTRACT NUMBER

CSD-1208 Res.

15. TYPE OF DOCUMENT

AID 590-1 (4-74)

# PROCEEDINGS OF THE

Held in Ankara, Turkey
29 April - 13 May 1970

# THIRD FAO/ROCKEFELLER FOUNDATION WHEAT SEMINAR

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

# PROTEIN IMPROVEMENT IN WHEAT1/

by

V.A. Johnson, J.W. Schmidt, and P.J. Mattern
(presented by V.A. Johnson)

## THE NUTRITIONAL QUALITY OF WHEAT

The world's population continues to increase each year. The increase is most rapid in the less-developed regions. There have been increases in food output (per capita), but they have not occurred uniformly throughout the world. In the less-developed countries where the need is greatest, production increases have not kept pace with population increases. Most of the world's better arable land already is being cultivated. Production increases, therefore, must come from increased yields.

Can wheat productivity be increased without depression of its nutritional quality? This is an important question, considering the role of wheat as one of the world's major food crops. Cooperative research on wheat protein by the Agricultural Research Service, USDA, and the University of Nebraska, with financial assistance from the Agency for International Development, U.S. Department of State, has provided useful information.

The nutritional quality of wheat depends upon:

1. Amount of protein
2. Amino acid composition of the protein
3. Digestibility of the protein.

My discussion will be concerned with protein quantity in wheat and amino acid composition.

### 1. Protein Content

The protein content of wheat is strongly influenced by level of productivity and soil nitrogen availability. High yields of grain frequently are accompanied by depressed protein content of the grain. This is particularly so when soil nitrogen availability is limited. Whether it is possible to avoid protein depression associated with extremely high grain yields by application of large amounts of nitrogen, is not fully known.

The level of protein in wheat can be manipulated genetically. Our evidence comes from genetic studies of hybrid populations and successful transfer of the high protein trait from the donor Atlas 66 cultivar to productive hard winter wheats. We have obtained heritability estimates from grain protein in a cross of Atlas 66 X Wichita, as high as 0.83.

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1/ Cooperative investigation of the Nebraska Agricultural Experiment Station and the Crops Research Division, Agricultural Research Service, U.S. Department of Agriculture.

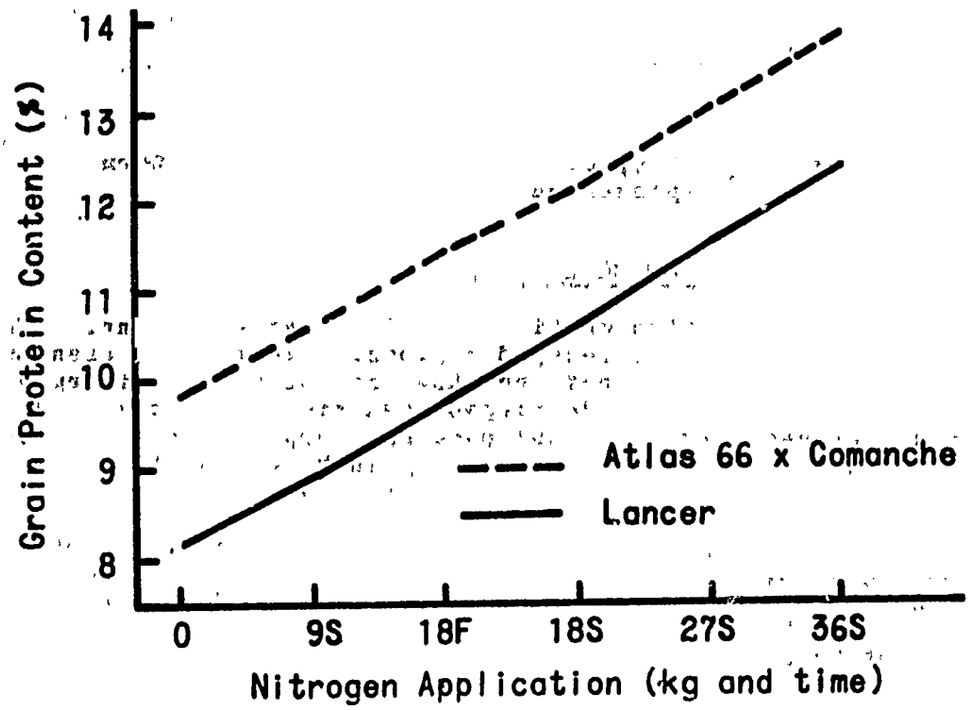


Figure 1. Effect of nitrogen fertilizer application on the protein content of NB65307 and Lancer at test sites in western Nebraska in 1968 (S = spring application; F= autumn application)

Several presumably different genetic sources of high protein have been identified. Those being used in our research programme at the University of Nebraska are shown in Table 1. We have used the Atlas 6 (Frondoso) source the most extensively. A gene for high protein in Atlas 66 is linked with a leaf rust resistance gene (Table 2). There i phenotypic expression of the resistance gene only in the adult plant stage.

TABLE 1.

SOURCES OF HIGH PROTEIN IN WHEAT BEING UTILIZED IN THE ARS-NEBRASKA RESEARCH PROGRAMME

| Cultivar | Growth Habit |
|---|---|
| Atlas 66 | Intermediate |
| Atlas 66-derived lines | Winter |
| Fertility Restorer 542437 | " |
| Aniversario-derived lines | " |
| Ky 58-Nth x Cnn-Tm-Mi-Hope lines | " |
| C.I. 6225 (Hybrid English) | " |
| P.I. 176217 (Nap Hal) | Spring |

TABLE 2.

GRAIN PROTEIN FREQUENCY DISTRIBUTION OF $F_6$ ROWS OF ATLAS 66 X COMANCHE HOMOZYGOUS FOR REACTION TO LEAF RUST IN THE ADULT PLANT STAGE

| Population | % grain protein (class centres) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 9.5 | 10.5 | 11.5 | 12.5 | 13.5 | 14.5 | 15.5 | 16.5 | 17.5 | 18.5 |
| Wichita (susc.) | | 1 | 10 | 1 | | | | | | |
| Susc. $F_6$ rows | 1 | 3 | 12 | 61 | 121 | 60 | 30 | 8 | 2 | |
| Res. $F_6$ rows | | | 2 | 6 | 8 | 18 | 35 | 89 | 7 | 29 |
| Atlas 66 (res.) | | | | | | | | | | 2 |

Some researchers have suggested that genes for high protein in wheat may not be expressed phenotypically in highly favourable environments in which there would be maximum utilization of available soil nitrogen for grain yield. Our data refute this suggestion. That phenotypic expression of high protein genes need not be associated with depressed grain yields is evident from the data in Table 3. The protein superiority of Atlas 66-derived families was expressed even though they were more productive than Comanche.

TABLE 3.

THREE-YEAR AVERAGE YIELD AND GRAIN PROTEIN CONTENT OF COMANCHE AND $F_2$-DERIVED FAMILIES FROM ATLAS 66 X COMANCHE

| Cultivar of Family | Av. yield of grain (kg/h) | Av. protein content of the grain (%)1/ |
|---|---|---|
| Comanche | 1 947 | 15.2 |
| 317 | 2 215 | 18.6 |
| 309 | 2 618 | 18.4 |
| 326 | 2 282 | 18.4 |
| 308 | 2 215 | 18.3 |
| 320 | 2 819 | 17.8 |
| 325 | 2 350 | 16.9 |
| 312 | 2 484 | 16.7 |

1/ Grain protein expressed on a Dry Weight Basis.

Further evidence was obtained from the First International Winter Wheat Performance Nursery grown in 1969. Atlas 66 and Atlas 66 x Comanche, Selection NB67730, were substantially higher in protein than five other cultivars at 16 testing sites (Table 4). Grain yields of the seven cultivars were reasonably comparable. The protein advantage of Atlas 66 and NB67730 was maintained at Kabul, Afghanistan, where yields were very high, as well as at Kermanshah, Iran, where low grain yields were produced (Table 5).

TABLE 4.

MEAN GRAIN YIELD AND PROTEIN CONTENT OF 7 CULTIVARS AT 16 SITES OF THE 1ST IWWPN

| Cultivar | $\bar{x}$ yield (q/ha)1/ | $\bar{x}$ protein content (%) |
|---|---|---|
| Heine VII | 37 | 14.8 |
| Bankuti | 36 | 15.0 |
| Riley 67 | 36 | 14.2 |
| Yorkstar | 36 | 12.5 |
| NB67730 | 35 | 16.4 |
| Atlas 66 | 33 | 17.4 |
| Gaines | 31 | 12.8 |

1/ One quintal = 100 kg.

TABLE 5.

GRAIN YIELD AND PROTEIN CONTENT OF 7 CULTIVARS AT A HIGH-YIELDING AND LOW-YIELDING SITE OF THE 1ST IWWPN IN 1969

| Cultivar | Kabul, Afghanistan | | Kermanshah, Iran | |
|---|---|---|---|---|
| | Yield q/ha | Protein % | Yield q/ha | Protein % |
| Heine VII | 61 | 15.9 | 18 | 15.4 |
| Bankuti 1201 | 60 | 14.1 | 15 | 14.7 |
| Riley 67 | 50 | 14.5 | 13 | 14.7 |
| Yorkstar | 66 | 10.4 | 13 | 13.5 |
| NB67730 | 53 | 17.1 | 14 | 15.9 |
| Atlas 66 | 44 | 16.5 | 13 | 18.5 |
| Gaines | 46 | 10.8 | 11 | 14.0 |

Protein levels higher than those achieved with Atlas 66 genes may be possible. We have crossed high protein Atlas 66 derivatives with other high protein wheats (Table 1) to determine whether further genetic increases can be obtained.

Our protein studies also indicate that the physiological basis for high protein in our Atlas 66-derived lines is differential nitrogen translocation rather than nitrogen uptake. The high protein lines appear to translocate nitrogen from the foliage to the grain more efficiently and completely than low protein varieties with which they were compared. We have reasoned from our evidence that, since differential nitrogen uptake apparently is not involved, there should be expression of the high protein trait over a range of soil fertility levels.

2. Amino Acid Composition

Lysine, methionine, and threonine are in shortest supply among the essential amino acids in wheat protein. The imbalance of essential amino acids in wheat reduces the nutritional value of its protein. The normal lysine content of wheat protein is about 3.0 percent. It is estimated that approximately 4.2 percent lysine would be needed to bring it into balance with other amino acids.

We have systematically screened, at the University of Nebraska, over 15 000 wheats from the World Collection maintained by the Agricultural Research Service, USDA, for lysine differences. We have not yet an "opaque-2" gene in wheat. Our measurements from lysine have shown a range of 2 to 4 percent.

It is our practice to immediately test the stability of the high lys values by growing the suspect wheats in different environments. Most of the "high lysine" wheats have failed to maintain the high values initiall assigned to them from laboratory analyses of the World Collection samples We must conclude that the high lysine values of these wheats are largely non-genetic.

There have been some exceptions. A few wheats from the World Collec ion, when grown in different environments, have rather consistently given higher-than-normal lysine values. These may be useful for breeding purposes (Table 6). P.I. 176217 is of particular interest to us because it appears to be high in protein content as well.

TABLE 6.

TENTATIVE SOURCES OF ABOVE-NORMAL LYSINE IN WHEAT

| Name of pedigree | C.I. or P.I. No. | Habit of growth |
|---|---|---|
| Nap Hal | P.I.176217 | Spring |
| Pearl | C.I.3285 | " |
| April Bearded | C.I.7337 | " |
| Hybrid English | C.I.6225 | Winter |
| Fultz x Hungarian | C.I.11849 | " |
| Fultz Sel-Hungarian x Menturki-Fultz Sel. | C.I.12756 | " |

$F_2$ populations from crosses involving high protein and suspected high lysine, currently under study at the University of Nebraska, total 86 in number. In addition to these $F_2$ populations, we propagated 147 $F_1$ hybrid combinations in the greenhouse in 1970. We are especially interested in the following populations which will be studied in some detail:

$F_2$ P.I.176217 x Atlas 66
" x Jang Kwang
" x Lancer
" x Trader
Pearl x Azteca
" x (Jang Kwang x Atlas 66-Cmn-Wrr) $F_1$
" x Ky 58-Nth-Cnn-Mi-Hope
$F_1$ P.I.176217 x 8156CR
" x C.I.13449

3. Effect of High Protein on Amino Acid Balance

Our analysis of the World Collection of Wheats indicates a negative relationship between level of protein and lysine content of the protein. This may be seen in Figure 2. The shaded area shows the range of disper of individual values about the mean. The protein differences among wheats in the World Collection were large (10 to 20%) but predominantly non-genetic. Clearly then, non-genetic increases in protein can be expected to affect adversely the lysine content of the protein.

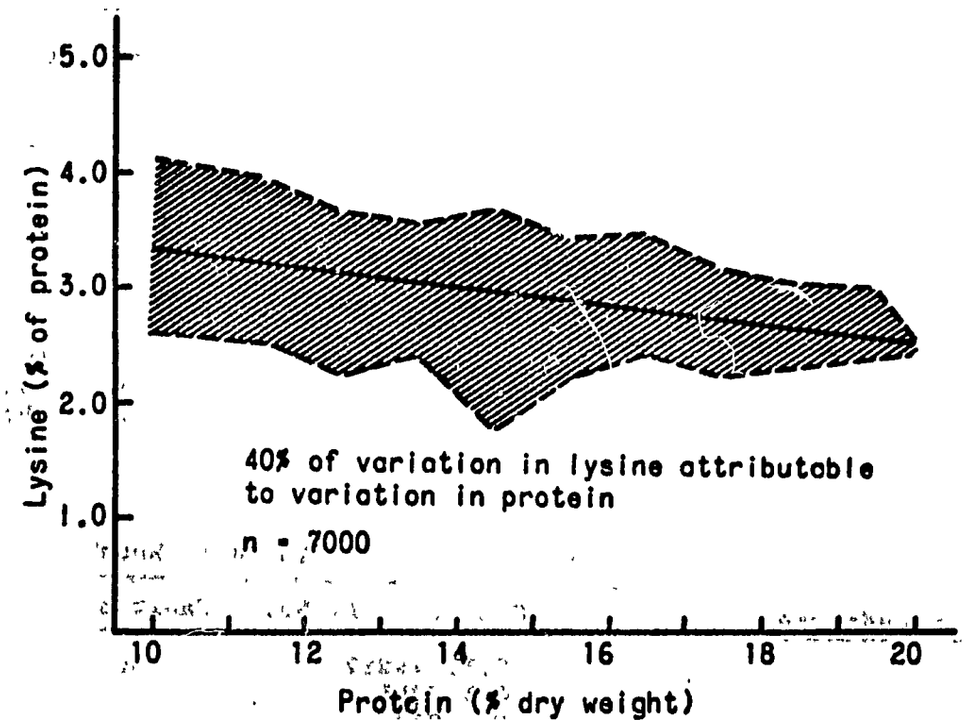


Figure 2. The relationship of grain protein content to lysine content among wheats in the World Collection.

A much more critical consideration for those engaged in nutritional improvement of wheat by breeding, is the effect of genetically high protein on amino acid balance. We have analysed many of our high protein Atlas 66-derived lines for lysine, methonine, and threonine, as seen in Table 7. Substantial increases in protein in the Atlas 66-derived lines were not associated with depression of the three essential amino acids measured, in most of the lines. On the basis of these and other data from our laboratory, we believe that genetic improvement of protein content in wheat need not be associated with undesirable shifts in the balance of essential amino acids.

We further assessed the contribution to nutritional value of the high protein in our Atlas 66-derived lines by calculating the increase of lysine, methionine, and threonine in a given weight of grain, over the low protein parent cultivar (Table 8). Assuming that there was no change in protein digestibility, all of the high protein lines provided more of the three essential amino acids per weight of grain than their Comanche parent. Such wheats would be nutritionally superior to Comanche.

TABLE 7.

LYSINE, METHIONINE, AND THREONINE CONTENT OF ATLAS 66-DERIVED HIGH PROTEIN LINES AND PARENT CULTIVARS

| Cultivar | Laboratory number | % Protein content 1/ | Amino acid content (g/16 g N) 1/ Lysine | Methionine | Threonine |
|---|---|---|---|---|---|
| Atlas 66 | 65-1 825 | 15.8 | 2.6 | 1.4 | 2.6 |
| Comanche | 1 556 | 12.3 | 2.7 | 1.5 | 3.5 |
| Atl 66 x Cmn | 1 557 | 15.4 | 2.4 | 1.4 | 3.4 |
| " | 1 558 | 14.3 | 2.7 | 1.4 | 3.6 |
| " | 1 559 | 15.6 | 2.7 | 1.4 | 3.5 |
| " | 1 560 | 16.1 | 2.5 | 1.3 | 3.3 |
| " | 1 561 | 14.8 | 2.6 | 1.4 | 3.6 |
| " | 1 562 | 15.8 | 2.5 | 1.3 | 3.3 |
| " | 1 563 | 16.4 | 2.3 | 1.3 | 3.5 |
| " | 1 564 | 14.5 | 2.7 | 1.5 | 3.3 |
| " | 1 565 | 14.6 | 2.7 | 1.4 | 3.5 |

1/ 14% moisture basis.

TABLE 8.

PERCENTAGE INCREASE IN LYSINE, METHIONINE, AND THE THREONINE IN A GIVEN WEIGHT OF GRAIN OVER THE LOW PROTEIN PARENT CULTIVAR, FROM HIGH PROTEIN ATLAS 66-DERIVED LINES

| Cultivar | Laboratory number | % increase in given weight of grain over low protein parent cultivar 1/ Lysine | Methionine | Threonine |
|---|---|---|---|---|
| Atlas 66 x Comanche | 65-1 557 | 25 | 19 | 20 |
| " | 1 558 | 15 | 6 | 17 |
| " | 1 559 | 33 | 17 | 24 |
| " | 1 560 | 20 | 18 | 22 |
| " | 1 561 | 15 | 12 | 22 |
| " | 1 562 | 19 | 9 | 22 |
| " | 1 563 | 15 | 14 | 32 |
| " | 1 564 | 18 | 16 | 9 |
| " | 1 565 | 18 | 11 | 19 |

1/ Calculated values rounded to nearest whole percent.

## OUTLOOK

The protein content of wheat can be increased by breeding. Since protein increases derived from Atlas 66 do not appear to be associated with unfavourable shifts in the balance of the most limiting essential amino acids lysine, methionine, and threonine, they would contribute significantly to nutritional value. The outlook for nutritional improvement via improved amino acid balance is less optimistic. Lysine differences detected by our laboratory have been mostly non-genetic. Genetic differences in lysine which may be present in a few of the wheats, have been relatively modest in magnitude.