AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY

1. SUBJECT CLASSIFICATION

A. PRIMARY
Agriculture

AF30-0180-0000

B. SECONDARY
Plant breeding--Cereals--Wheat

2. TITLE AND SUBTITLE
Development and utilization of productive nutritious wheat varieties

3. AUTHOR(S)
Johnson,V.A.

4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1974	26p.	ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS
Neb.

8. SUPPLEMENTARY NOTES *(Sponsoring Organization, Publishers, Availability)*
(Presented at 1st annual meeting,World Population Soc.,Washington,D.C.)

9. ABSTRACT

10. CONTROL NUMBER
PN-RAA- 262

11. PRICE OF DOCUMENT

12. DESCRIPTORS
Nutritive value
Proteins
Wheat
Yield

13. PROJECT NUMBER

14. CONTRACT NUMBER
CSD-1208 Res.

15. TYPE OF DOCUMENT

AID 590-1 (4-74)

DEVELOPMENT AND UTILIZATION OF PRODUCTIVE NUTRITIOUS WHEAT VARIETIES[1]

by
V. A. Johnson[2]

Introduction

Wheat and other cereal grains are seldom identified as protein foods because of their relatively low protein content and amino acid imbalance. Yet wheat and rice, the two major food cereals, are the principal providers of both calories and protein for two-thirds of the world's people. Nutritionists have demonstrated that both cereal species can adequately satisfy the protein as well as the calorie requirements of adult humans.

Protein deficiency is a major nutritional problem. A related and perhaps an equally serious problem is an acute shortage of calories in many developing countries where inadequate food supplies are chronic. People require protein for tissue synthesis and body growth. Sugars, fats, and other carbohydrates provide the calories needed for energy. Protein deficiency accompanied by calorie deficiency is difficult to correct. Protein given to a malnourished person is likely to be converted to energy and little of it will be used for growth. Thus,

[1]Presented by V. A. Johnson at a Symposium on Breakthroughs in the Production and Utilization of Protein Foods, World Population Society, February 7, 1974, Washington, D. C. Published as Paper No. 3757, Journal Series, Nebraska Agricultural Experiment Station.

[2]Research Agronomist, U. S. Department of Agriculture, Agricultural Research Service, North Central Region, and Professor of Agronomy, University of Nebraska, Lincoln, Nebraska.

TO TYPISTS—Begin typing flush with the left-hand marginal line, and end typing so the average length of lines corresponds with the right-hand marginal line

productivity cannot be dismissed in efforts to improve the nutritional value of cereals.

The alarming near-exponential increase in world population is likely to be accompanied by increasing nutritional dependence on the food cereals. In developing countries where already there is heavy reliance on the cereals, population is growing twice as fast as in the developed sector of the world. By the year 2000 it is estimated that less than 25% of the total world population will belong to the developed sector. In developing countries food production is not keeping pace with increasing population with the result that per capita food output is declining. Disaster has been largely avoided by increased per capita food output of the developed world.

People in the United States and Northern Europe obtain a substantial portion of their protein and calories from protein foods like meat and animal products. The opposite is true in the developing countries. There is little likelihood that a shift to animal protein can occur in a major part of the world where overpopulation is a problem because wheat and other cereals are more efficient producers of protein as well as calories than is livestock. Fortunately, wheat, rice, maize, and sorghum are well established in the diets of people who must depend on them and their acceptance in diets is not a problem. Advances, then, in the productivity and nutritional quality of the cereals must have far-reaching significance.

Productivity

The high price of wheat on the world market reflects its high

demand. Some have attributed the situation to decreasing world production of wheat. Actually there has been a steady increase in world wheat production from 1961 until 1973 (table 1) when there were 400 million fewer bushels produced than in 1972. The 1974 world wheat production estimate stands at 13 billion bushels.

Increased world wheat production has been in part associated with higher yields (table 2). Each country or region shown recorded a substantial increase in average wheat yield in 1970 over its 1964-1968 5-year average. Yield increases have been spectacular in countries like Mexico, India, and Pakistan during the period. In the latter two countries the "green revolution" produced increases approaching 50%.

This miracle in wheat and rice productivity has been identified by some as merely the result of the introduction and widespread use of high yielding semidwarf varieties. It was much more than that. The "green revolution" involved the use of productive semidwarf varieties in combination with vastly improved production practices -- particularly fertilizer and water. The 50% increase in average wheat yields in India and Pakistan can be attributed to this variety-production package.

By 1970, 40% of all wheat acreage in India and Pakistan was occupied by the new semidwarf varieties (table 3). Nearly 25 million acres of these wheats were in production in seven Asian countries by 1970. Further increases have occurred since 1970. In Mexico where the initial "green revolution" semidwarf varieties weredeveloped, the

TO TYPISTS—Begin typing flush with the left-hand marginal line, and end typing so the average length of lines corresponds with the right-hand marginal line

Table 1.--World wheat production.

Year	Billions of bushels
1960-61	8.8
1970-71	11.3
1971-72	12.5
1972-73	12.1 (prelim.)
1973-74	13.0 (est.)

TO TYPISTS—Begin typing flush with the left-hand marginal line, and end typing so the average length of lines corresponds with the right-hand marginal line

Table 2.--World wheat yields (bu/a).

	1964-68	1970
USA	26.6	31.2
USSR	14.3	16.4
East Europe	33.5	35.3
West Europe	36.8	38.1
Mexico	34.5	44.1
India	13.3	18.6
Pakistan	12.8	17.5

TO TYPISTS—Begin typing flush with the left-hand marginal line, and end typing so the average length of lines corresponds with the right-hand marginal line

Table 3.--Acreage of high yielding semidwarf varieties in Asia, 1970.

Country	Acres	Est. % of total acreage
India	15,100,000	38
West Pakistan	7,000,000	45
Turkey	1,540,000	8
Afghanistan	360,000	6
Iran	222,000	2
Nepal	186,000	-
Lebanon	4,200	3
Total	24,412,200	-

TO TYPISTS—Begin typing flush with the left-hand marginal line, and end typing so the average length of lines corresponds with the right-hand marginal line

average wheat yield rose to 44 bushels per acre in 1970. The yields in Mexico resulting from the new variety-production package are now among the highest in the world.

The trend toward short-statured wheat varieties has occurred throughout the world. By 1969, more than one-half of the wheat acreage of the Pacific Northwest region of the United States was occupied by semidwarf varieties. Short varieties now dominate Southeastern United States. Bezostaya, a Russian variety that has dominated the acreage of Southern Russia and Eastern Europe, is a moderately-short, stiff-strawed variety. Yugoslavia and Bulgaria have recently developed excellent new short varieties. Western European countries have grown this type of variety for many years.

Protein Content

The large effort in wheat improvement throughout the world, until recently, has been to make wheat more productive. Concern over the nutritional quality of wheat is more recent. Prior to 1955 there was little research effort to improve the nutritional status of wheat and other cereals. The Agricultural Research Service, U. S. Department of Agriculture, in cooperation with the University of Nebraska, pioneered in research to improve the nutritional value of wheat. In the beginning we were concerned with increasing protein content. In 1966 contract funds from the U. S. Agency for International Development to the University of Nebraska enabled us to expand our research to include modification of wheat protein composition.

Initially, we had to establish the existence of major genes for

TO TYPISTS—Begin typing flush with the left-hand marginal line, and end typing so the average length of lines corresponds with the right-hand marginal line

protein in wheat and their transferability from one variety to another. Such genes were identified in Atlas 50 and 66, soft red winter wheat varieties from North Carolina. From crosses of Atlas 66 with bread wheat varieties we were able to select lines with as much as 3 percentage points higher protein in their grain than ordinary varieties (table 4). Unfortunately, selections from the first cycle of breeding for high protein were not as productive as commercially grown varieties like Scout and it was necessary to continue into the second breeding cycle.

Grain yield and protein content of some second cycle lines at three Nebraska test sites in 1970 are shown in table 5. These were equal to or higher yielding than Scout 66 and all maintained more than 2 percentage points protein advantage over Scout 66. One of these lines, NE701132, is undergoing seed increase for possible release as a commercial variety to Nebraska wheat growers next year. It is also being performance tested in several Asian countries. The Nebraska Agricultural Experiment Station officially released 26 high protein lines of wheat in 1971 for use by breeders as elite germplasm.

The high protein capability of Atlas 66-derived wheats is expressed in many different production environments. This was demonstrated in an International Winter Wheat Performance Nursery organized by the ARS-Nebraska wheat team in 1969 (table 6). NE67730 maintained a protein advantage of 1.9 to 4.4 percentage points at such widely different production sites as Stillwater, Oklahoma; Martonvasar, Hungary; and Cambridge, England.

TO TYPISTS—Begin typing flush with the left-hand marginal line, and end typing so the average length of lines corresponds with the right-hand marginal line

Table 4.--Average grain yield and protein content of two high protein lines of winter wheat derived from Atlas 66 compared with the commercial variety Scout at Lincoln, Nebraska, 1962-64.

Variety	Grain yield (bu/a)	Protein content[1] (%)
Scout	41	13.6
NE60306	38	16.1
NE60305	36	16.5

[1]Computed at 14% moisture level.

TO TYPISTS—Begin typing flush with the left-hand marginal line, and end typing so the average length of lines corresponds with the right-hand marginal line

Table 5.--Mean yield and protein content of selected high protein lines from the second breeding cycle in comparison with Scout 66 at 3 Nebraska test sites in 1970.

Variety	C.I. or Sel. No.	$\bar{x}$ grain yield (bu/a)	$\bar{x}$ protein content[1] (%)
Scout 66	13996	34.6	11.8
Atlas 66/Cmn//Lancer	701132	39.6	14.4
"	701134	36.8	14.3
"	701137	36.0	14.1
Lancer//Atlas 66/Cmn	70654	33.8	14.4

[1]Computed at 14% moisture level.

TO TYPISTS—Begin typing flush with the left-hand marginal line, and end typing so the average length of lines corresponds with the right-hand marginal line

Table 6.--Expression of the high protein trait of NE67730 grown in the International Winter Wheat Performance Nursery at Stillwater, Oklahoma; Martonvasar, Hungary; and Cambridge, England in 1970.

Variety	Grain protein content (%) at: 1/		
	Stillwater Oklahoma	Martonvasar Hungary	Cambridge England
Atlas 66/Cmn (NE67730)	20.9	18.4	14.2
Bezostaya 1	16.5	14.3	12.3
Lancer	16.2	14.6	12.1
Yorkstar	16.0	13.7	11.2
Gaines	16.5	14.1	10.6
Nursery $\bar{x}$	17.8	15.8	12.5

1/ Computed on dry grain weight basis.

TO TYPISTS—Begin typing flush with the left-hand marginal line, and end typing so the average length of lines corresponds with the right-hand marginal line

The level of protein in wheat is strongly affected by soil fertility. We tested the performance of the high protein line, C.I. 14016, and Lancer under different levels of nitrogen fertilizer application at low fertility test sites in Nebraska (table 7). Both varieties responded strongly to increments of nitrogen fertilizer with higher grain protein content and somewhat higher grain yield. Throughout the entire range, C.I. 14016 maintained a protein advantage over Lancer of approximately 2 percentage points.

We have reason to believe that we have only begun to exploit the high protein possibilities in wheat. Our laboratory has analyzed over 13,000 common wheats from a World Collection maintained by the Agricultural Research Service, U. S. D. A. Protein values among these wheats ranged from only 8% to 22%. Much of this variation can be attributed to non-genetic causes. However, we believe the genetic component to be as much as 5 percentage points. This can be fixed in new varieties.

Recently we crossed two high protein varieties, Atlas 66 and Nap Hal. Apparent transgressive segregation for high protein occurred in the progeny (figure 1). We identified some F_2-derived progeny bulk rows with grain protein over 25% compared to 21 to 22% mean values for the parent varieties. We attribute this to different genes for high protein in Atlas 66 and Nap Hal that function additively when combined to produce new very high levels of protein. Protein values obtained from F_5 selections of Nap Hal/Atlas 66 in 1973 support this (table 8). Several produced grain with protein content 2

TO TYPISTS—Begin typing flush with the left-hand marginal line, and end typing so the average length of lines corresponds with the right-hand marginal line.

Table 7.--Average grain yield and protein content of a normal and a high protein wheat variety on different nitrogen fertility levels in Nebraska in 1969 and 1970.

Nitrogen applied (lb/a)	Grain yield (bu/a)		Protein content (%)	
	Lancer	C.I.14016	Lancer	C.I.14016
0	38	38	10.8	12.5
20	44	41	11.2	13.3
40	47	44	11.8	14.0
60	46	45	12.6	14.9
80	46	45	13.2	15.4
100	46	45	13.6	15.8
120	45	46	14.0	16.3

TO TYPISTS—Begin typing flush with the left-hand marginal line, and end typing so the average length of lines corresponds with the right-hand marginal line

Table 8.--F_5 selections from the cross Nap Hal/Atlas 66 that exhibit promising levels of grain protein.

Variety	Row no.	Protein (%)	Lysine/protein (%)	Adjusted lysine/protein (%)
Nap Hal	$\bar{x}$ of 9 rows	20.0	3.1	3.3
Atlas 66	$\bar{x}$ of 9 rows	19.9	2.8	3.0
Nap Hal/Atlas 66 F_5	15,138	24.2	2.8	3.0
"	14,169	23.7	2.9	3.1
"	15,164	23.7	2.9	3.0
"	11,602	23.4	3.1	3.2
"	11,444	23.2	3.1	3.3
"	12,926	22.5	3.0	3.2

TO TYPISTS—Begin typing flush with the left-hand marginal line, and end typing so the average length of lines corresponds with the right-hand marginal line

to 4 percentage points higher than the parent varieties.

In many countries wheat is milled into white flour for bread-making purposes. White flour comes from the endosperm portion of the wheat kernel. High protein wheat in these countries also would have to produce high protein white flour to be nutritionally useful. We separated grain from Atlas 66, Nap Hal, and two normal protein varieties, Bezostaya 1 and Centurk, into white flour and bran (table 9). The flour from both Atlas 66 and Nap Hal remained over 2 percentage points higher in protein content than the ordinary varieties.

Protein Quality

An important question for researchers who manipulate the amount of protein in wheat is what effect changes in protein level have on amino acid composition. Amino acids are the building blocks of protein. Their ratio and availability largely determine the nutritional value of protein, the utilization of which by the monogastric animal, is limited by that essential amino acid in shortest supply. In the case of wheat and other cereal grains lysine is in the shortest supply; thus is the key to improvement of their nutritional value.

Based on our analyses for protein and lysine of over 12,000 common wheats in the World Collection, we were able to demonstrate that the level of lysine in wheat protein is affected by the amount of protein. As protein in wheat grain increases, lysine expressed as percent of protein decreases. The negative relationship weakens as protein becomes higher and above 15% protein, it disappears altogether. The quality of the protein in high protein wheat could not be expected

TO TYPISTS—Begin typing flush with the left-hand marginal line, and end typing so the average length of lines corresponds with the right-hand marginal line

Table 9.--Protein content of whole wheat and white flour from four wheat varieties.

Variety	Protein content (%)[1]	
	Whole wheat	White flour
Nap Hal	18.3	16.1
Atlas 66	17.7	16.5
Centurk	15.0	13.7
Bezostaya 1	14.0	13.4

[1]Computed on dry grain weight basis.

TO TYPISTS—Begin typing flush with the left-hand marginal line, and end typing so the average length of lines corresponds with the right-hand marginal line

to be as good as that in low protein wheat because of lower lysine content.

More important from the nutritional point of view is the amount of lysine per unit weight of grain in a high protein sample as compared with the amount in a low protein sample. Lysine expressed on this basis increases as the amount of protein in a sample increases. This suggested to us that high protein wheat should be better nutritionally than low protein wheat. In mouse bioassays conducted at the University of Nebraska in which many of our high protein lines were the sole source of protein in the ration, the high protein wheats produced higher mice weight gains on the average than did lower protein wheats (table 10).

Highly significant genetic breakthroughs to nutritional improvement have occurred in maize, barley, and sorghum in which genes that promote lysine levels equal to the needs of man and non-ruminant animals have been identified. These cereals are diploid species in contrast to food wheats which are hexaploid or tetraploid. Possible masking effects attributable to the second and third genomes in wheat may account for the failure to date to detect genetic variation for lysine in wheat protein of the same order of magnitude as that identified in the diploid cereal species.

Our systematic analysis of 17,000 hexaploid and tetraploid wheats in the World Collection has uncovered genetic variation for lysine level of approximately 0.5% where lysine is expressed as percent of protein. The normal level of lysine in wheat is 3.0%. We believe

TO TYPISTS—Begin typing flush with the left-hand marginal line, and end typing so the average length of lines corresponds with the right-hand marginal line

Table 10.--Mean weight gains from wheat samples differing in protein content when fed to weanling mice for a 28-day period (5 mice per sample).

No. of samples	Protein range (%)	Mean protein (%)	Mean weight gain (g)
14	17.0-18.6	17.5	15.1
16	15.1-16.8	16.1	12.9
14	13.5-14.8	14.3	13.5
5	10.8-12.9	11.7	10.2

TO TYPISTS—Begin typing flush with the left-hand marginal line, and end typing so the average length of lines corresponds with the right-hand marginal line

that 4.2% lysine is required to bring it into reasonable balance with other essential amino acids in wheat protein. Although the 0.5% variability in lysine detected by us to date is less than one-half the amount of increase needed, we believe it to be of sufficient magnitude to be useful in breeding improvement of wheat quality.

Common wheats with the highest lysine values in the World Collection are listed in table 11. By adjusting lysine to a common level of protein we overcome most of the effect of protein on lysine. This permits lysine comparisons among wheats that differ in protein content. C.I.13449 produced the highest lysine value among 12,600 common wheats but was lower in protein content than most of the wheats.

From a cross of C.I.13449 with Nap Hal, which also is above normal in lysine, we obtained F_2 progeny rows that were higher in adjusted lysine than either parent variety (figure 2). Selections from several of these high protein progeny rows were again higher in adjusted lysine than Nap Hal in 1973 (table 12). Some of the selections exhibited excellent levels of both protein and lysine. Small animal bioassays will be conducted on the selections to assess the contribution of the above-normal level of lysine to improved nutritional value.

International Cooperation

An effective international network for the nutritional improvement of wheat now exists (figure 3). New useful germplasm and research information from our program and elsewhere flow freely among international organizations and developing countries. We have filled 55 seed requests for our wheat stocks from 28 foreign countries as

TO TYPISTS—Begin typing flush with the left-hand marginal line, and end typing so the average length of lines corresponds with the right-hand marginal line.

Table 11.--Promising high lysine wheats from the World Collection.

P.I. or C.I. no.	Protein content(%)	Lysine per unit protein(%)	Adj. lysine per unit protein(%)	Deviation from normal(%)
13449	9.2	4.2	3.7	+ 0.5
9364	11.5	3.8	3.7	+ .05
271075	15.1	3.5	3.6	+ 0.5
10517	14.5	3.5	3.6	+ 0.5
94460	12.4	3.6	3.6	+ 0.5
117628	15.8	3.4	3.6	+ 0.5
94504	12.6	3.6	3.6	+ 0.5
13447	10.3	3.9	3.6	+ 0.5

TO TYPISTS—Begin typing flush with the left-hand marginal line, and end typing so the average length of lines corresponds with the right-hand marginal line

Table 12--F_4 selections from Nap Hal/C.I.13449 that exhibit combined high protein and high lysine in their grain.

Variety	Row no.	Protein (%)	Lysine/protein (%)	Adjusted lysine/protein (%)
Nap Hal	$\bar{x}$ of 26 rows	17.5	3.2	3.4
Nap Hal/CI13449(F_4)	16,900	19.4	3.4	3.6
"	16,927	17.8	3.4	3.6
"	16,921	17.7	3.4	3.6
"	18,640	16.8	3.4	3.6
"	17,330	16.2	3.6	3.8
"	16,442	15.3	3.5	3.7

TO TYPISTS—Begin typing flush with the left-hand marginal line, and end typing so the average length of lines corresponds with the right-hand marginal line

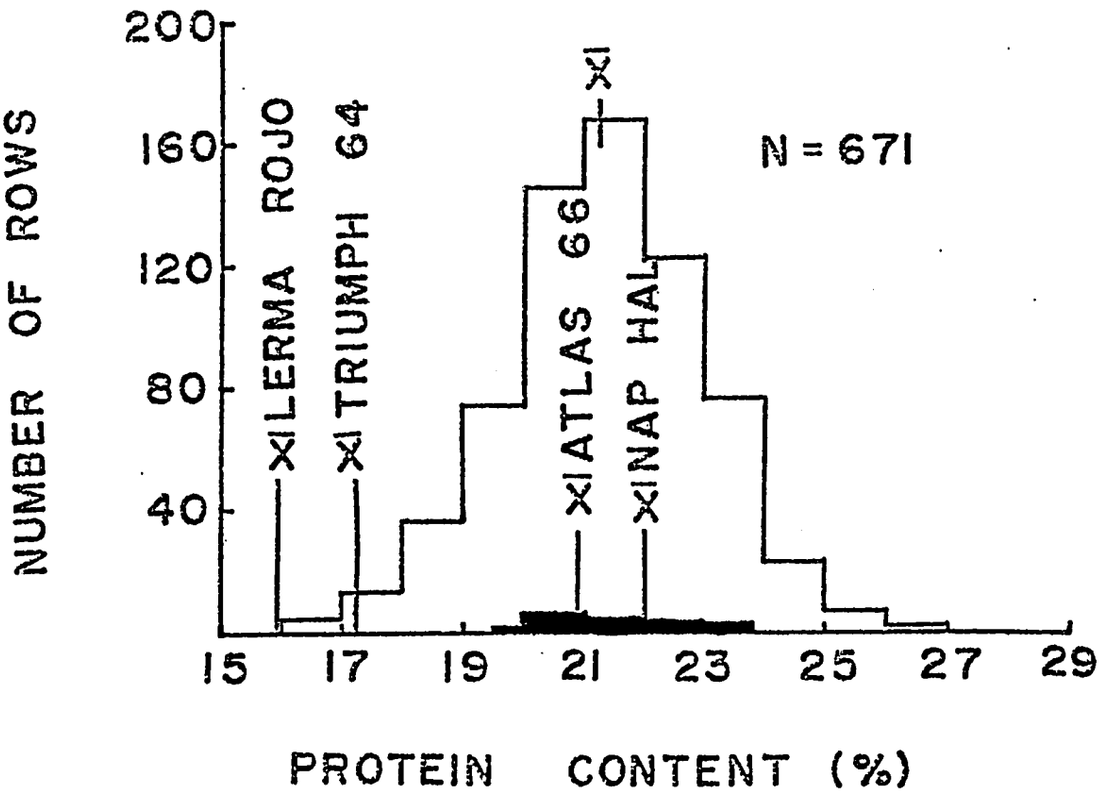
NUMBER OF ROWS
200
160
120
80
40
LERMA ROJO
TRIUMPH 64
ATLAS 66
NAP HAL
N = 671
15
17
19
21
23
25
27
29
PROTEIN CONTENT (%)

Figure 1.

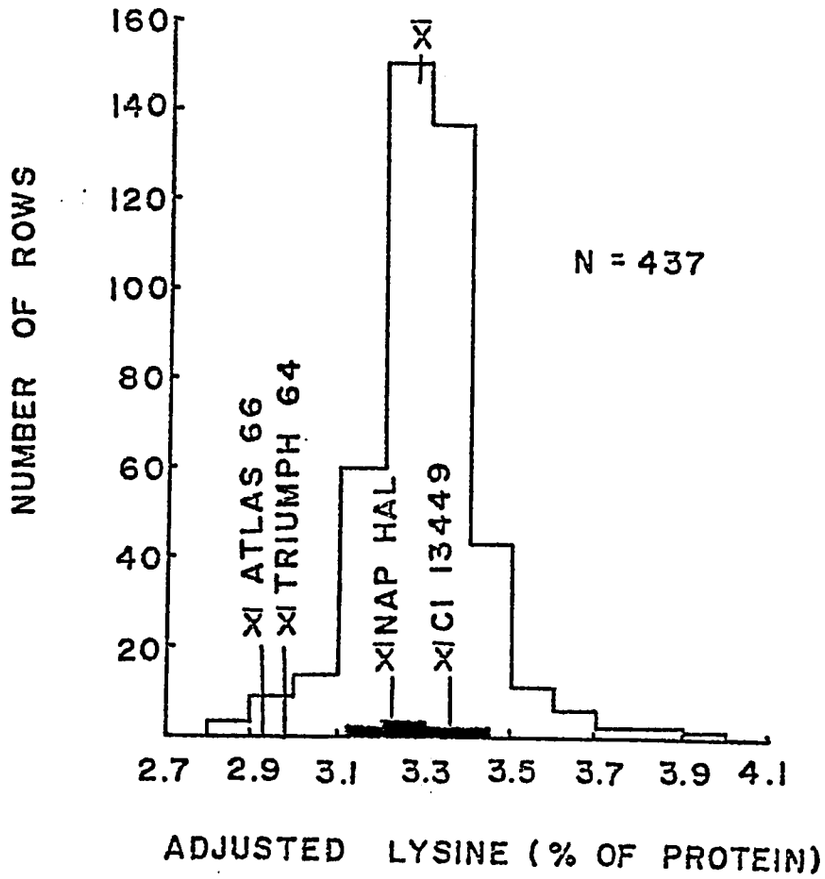
NUMBER OF ROWS
160
140
120
100
80
60
40
20
N = 437
ATLAS 66
TRIUMPH 64
NAP HAL
CI 13449
2.7
2.9
3.1
3.3
3.5
3.7
3.9
4.1
ADJUSTED LYSINE (% OF PROTEIN)

Figure 2.

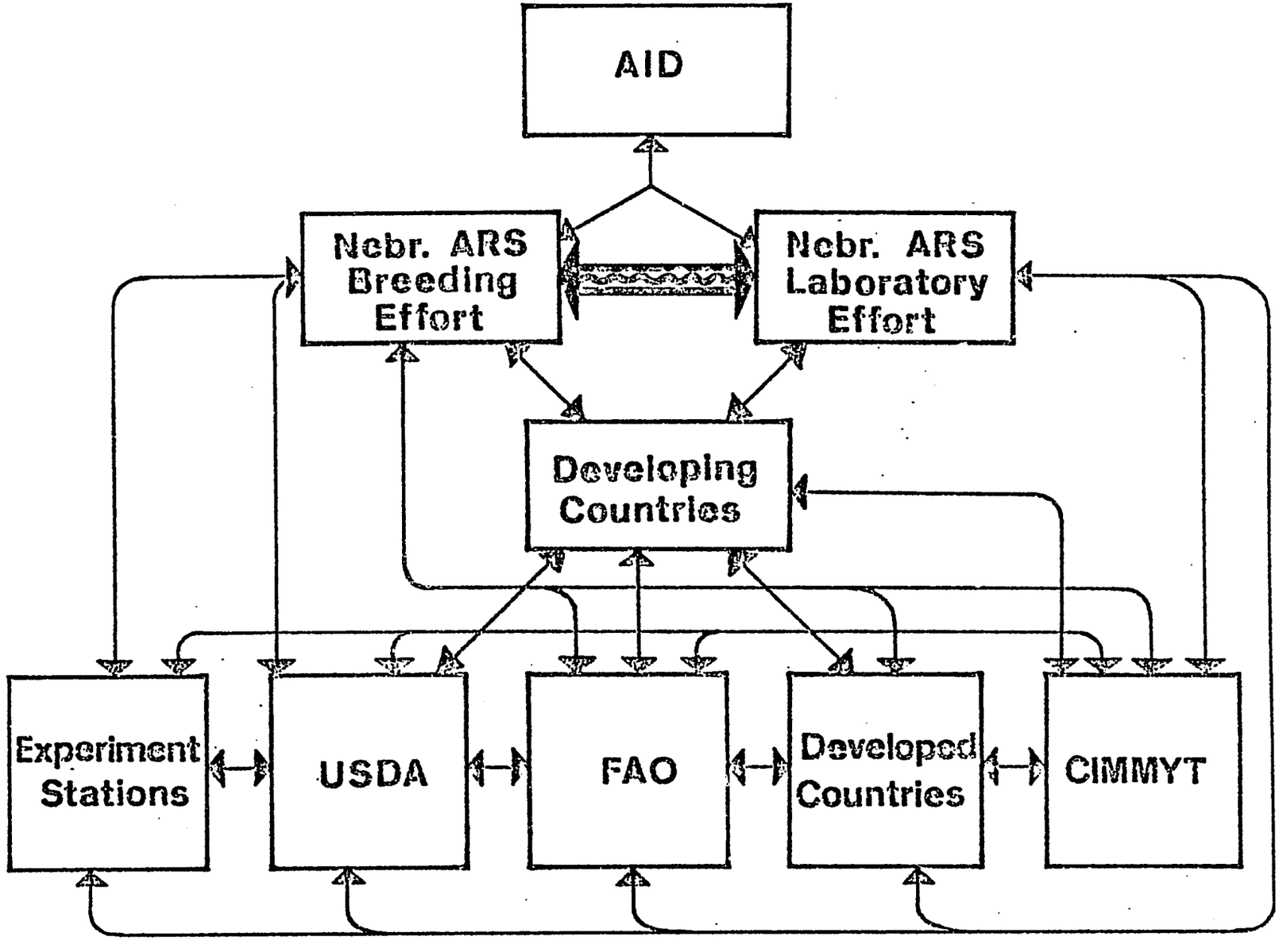
AID
Nebr. ARS Breeding Effort
Nebr. ARS Laboratory Effort
Developing Countries
Experiment Stations
USDA
FAO
Developed Countries
CIMMYT

Figure 3.

well as 57 requests from researchers in the United States.

We annually evaluate new wheat strains from our own program and from other countries in an International Winter Wheat Performance Nursery organized by us in 1969. Thirty varieties now are tested each year at 55 locations in 35 different countries. The nursery network permits rapid evaluation of new wheat varieties for productivity and nutritional quality. It already has led to the commercial use of some of these varieties in some Near- and Middle-East countries where hunger is chronic.

We are continuing our cooperative effort at the University of Nebraska to develop wheats that are more productive and more nutritious. We are confident that, with time, it can be done. Projections of 5 billion people by 1985 cause our optimism to be tempered by the realization that, unless this projected population growth is somehow checked, we may be merely buying time with any successes in providing more and better wheat.

TO TYPISTS—Begin typing flush with the left-hand marginal line, and end typing so the average length of lines corresponds with the right-hand marginal line

Captions

Figure 1. Protein frequency distribution for F_2 progeny bulk rows from the cross Nap Hal/Atlas 66.

Figure 2. Adjusted lysine frequency distribution for F_2 progeny bulk rows from the cross Nap Hal/C.I.13449.

Figure 3. International research information and germplasm network for the nutritional improvement of wheat.

TO TYPISTS—Begin typing flush with the left-hand marginal line, and end typing so the average length of lines corresponds with the right-hand marginal line