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9. ABSTRACT

Workshop's papers on progress, problems, and potential for the improvement of various crops and the task group's recommendations for future operations and research. General conclusions and recommendations are not offered. Besides a general task group, there are groups representing wheat, rice, and corn, sorghum, and millet. Papers discussing breeding, fortification, and utilization of these crops also are included, as well as one on alternative carriers for fortification (salt). The working papers cover the topics of the economics of protein strategies; brief overviews of plant breeding and fortification; pulse production, status, and potential; and meeting protein and amino acid requirements of man.

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IMPROVING THE NUTRIENT QUALITY OF CEREALS

Report of Workshop on Breeding and Fortification

June 1971

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Washington, D.C. 20523

IMPROVING THE NUTRIENT QUALITY OF CEREALS

Report of Workshop on
Breeding and Fortification

Annapolis, Maryland
December 7-9, 1970

Convened by

The Office of Nutrition, Technical Assistance Bureau
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TABLE OF CONTENTS

	Page
INTRODUCTION	v
TASK GROUP REPORTS	
1. Report of General Task Group	1
2. Report of Task Group on Wheat	5
3. Report of Task Group on Rice	9
4. Report of Task Group on Corn, Sorghum and Millet	15
APPENDIX	
WORKING PAPERS	
1. Economics of Protein Strategies by Lyle Schertz	A-1
2. Plant Breeding, Brief Overview by G. F. Spraque	A-9
3. Fortification, Brief Overview by Aaron Altschul	A-13
4. Pulse Production, Status and Potential by P. H. van Schaik	A-19
5. Meeting Protein and Amino Acid Requirements of Man by Helen Clark	A-25
WHEAT	
1. Breeding by V. A. Johnson	A-29
2. Fortification by Daniel Rosenfield	A-33
RICE	
1. Breeding by H. M. Beachell	A-39
2. Fortification by Stanley Gershoff	A-55

Page

CORN

1. Breeding by G. F. Spraque A-59

2. Problems of Utilization by H. C. Frost A-63

3. Fortification - Experience by Ricardo Bressani A-69

4. Fortification - Recommendations by Paul LaChance A-75

SORGHUM AND MILLET

1. Breeding-- Sorghum by R. C. Pickett A-77

2. Breeding - Millet by Glenn Burton A-81

ALTERNATIVE CARRIERS FOR FORTIFICATION

Salt by James Levinson A-85

ANNEXES

A. PROGRAM OF THE WORKSHOP AA-1

B. LIST OF WORKSHOP PARTICIPANTS AA-4

C. TASK GROUP CHAIRMEN AND RAPPORTEURS AA-7

INTRODUCTION

In 1967 the President's Science Advisory Committee pointed up the potential for effecting improvement in diet through the breeding of higher protein content and quality in staples and through fortification of such staples during the milling process. That same year these two techniques were also included in recommendations to avert the protein crisis made by the United Nations Advisory Committee on the Application of Science and Technology to Development.

Efforts in these areas had been initiated earlier, but in the past few years, the pace of progress has been accelerated. Higher protein strains of the major cereals have been developed. Field trials have been initiated to test the feasibility of fortification of wheat, rice and corn. Synthetic amino acid technology has progressed, and prices have dropped. Research and development is being augmented. As work progressed, it became apparent that there could be great mutual benefit from improved intercommunication among breeders, nutritionists, food technologists and economists.

Accordingly, arrangements were made to bring together individuals working in the fields of breeding and fortification in a joint meeting for a mutual briefing on the state of developments in both fields to exchange views, to examine opportunities and problems, and to attempt to identify for researchers and financing organizations the nature and magnitude of new efforts that might be undertaken to enhance effectiveness and accelerate the pace of development.

These were the purposes of the Seminar on Breeding and Fortification convened at Annapolis, Maryland from December 7-9, 1970. This report contains working papers presented at the meeting on progress, problems and potential for the improvement of various crops and the recommendations developed by task groups for future operations and research.

We are grateful to the participants for the level of competence and dedication displayed at the Seminar and reflected in papers. It augers well for the future of cereal improvement. A dialogue has been initiated. By publication of these papers we hope to encourage its extension.

Harold L. Wilcke, Workshop Chairman
Vice-President
Ralston Purina Company

Martin J. Forman, Director
Office of Nutrition
Technical Assistance Bureau, AID

TASK GROUP REPORTS

REPORT OF GENERAL TASK GROUP

Breeding, plus improved agricultural practices, and fortification are not mutally exclusive. Rather they must be considered together in any strategy of improving the protein quantity and quality of foods. The following recommendations are made:

(1) AID should develop a joint Research and Development planning and evaluation group to:

a. Provide general guidance to ongoing AID supported agricultural and technological efforts to improve the nutritional quality of cereals by breeding and fortification. Such guidance would be directed at improving nutrition, cost, processing and distribution.

b. Initiate, as appropriate, pilot studies in several countries on the development of a food strategy that takes into account agriculture, nutrition, and food technology. The purpose of these models would be to examine the entire system of possibilities for intervention in relation to the specific character and needs of a given country. (These studies could, with respect to fortification, also include, where desirable, consideration of other carriers in addition to grains, such as salt and tea.)

Page 3 contains a diagram of the functioning of the group.

(2) Joint efforts should be increased to improve the utilization of legumes. Increased yield and improved quality should be incorporated into new varieties by agricultural

methods. Food technology should be called upon to develop useful foods from these new varieties.

(3) Joint efforts should be increased to make greater use of oilseeds as a protein source for humans. Such oilseed proteins would be derived from soy, peanuts, cotton, sunflower rape, sesame, oil palm, coconut oil, and others.

Organizational Structure and Function of

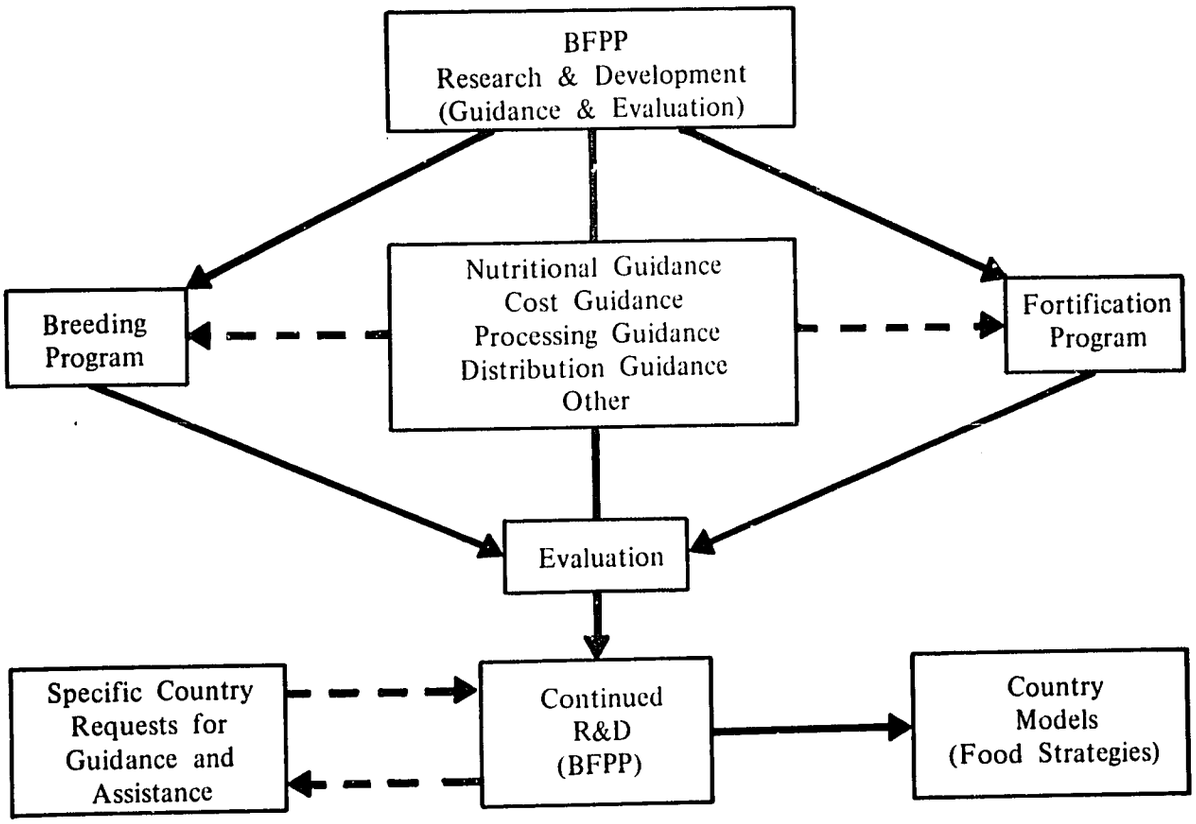
Committee on Breeding and Fortification

a. Membership will consist of AID personnel and consultants as appropriate.

b. The group will encompass a variety of disciplines. And it should make provision for geographic bureau representation.

c. There will be a mechanism to link the efforts of the planning group with operational program personnel in order to determine ultimate relevance of research or other activities planned to actual program and country needs.

Committee on Breeding and Fortification – Policies and Programs (BFPP)



REPORT OF TASK GROUP ON WHEAT

The sub-committee reported that *fortification* of wheat, either with micronutrients, lysine, or with protein concentrates, is in general technically, logistically, and economically feasible, particularly in central processing facilities which serve urban populations. Problems, however, may be encountered when concentrates are used. For example, concentrates derived from soy, peanut, cottonseed, fish, etc. can be highly variable in protein quality depending on processing conditions. In addition, the technology for the incorporation of these concentrates into foods in a manner acceptable to indigenous populations in the developing nations is still relatively primitive.

Breeding programs have had considerable success. The combination of proper genetic material and good agricultural practices can produce crops containing 20-25 percent more protein with no deterioration of the essential amino acid pattern. There is general agreement that research on genetic improvement leading to increases in protein quantity should receive first consideration. However, the search for high lysine wheat varieties should not be neglected. It is recognized that fortification with lysine can help meet protein requirements in regions where wheat serves as the mainstay of the diet.

The following *recommendations* calling either for research, action programs, and/or socio-economic feasibility evaluations are made:

(1) AID should initiate a project to improve current screening technology for mass

evaluation of improved nutritional quality in wheat. It is not enough to determine essential amino acids and protein quantity in the very large number of genotypes generated in these breeding programs. The new screening model should take into account availability of nutrients, protein fractions affected by genetic manipulation, identification and determination of the second limiting amino acid, and nutritionally important components other than protein that are present.

(2) AID supported studies at Nebraska have led to the introduction of high-protein traits in wheat varieties in several developing nations. Local evaluation and propogation of these new breeding materials call for an improved global distribution network. Such an expanded effort requires an international system for proper distribution of breeding materials, close follow-up of ongoing studies, and continuous support of developing nation efforts to adapt new varieties to local agricultural conditions, food use patterns and processing, and functionality requirements.

AID should therefore consider the feasibility of establishing, in cooperation with existing crop breeding organizations, an international wheat improvement network. This network should utilize existing AID - agriculture units abroad and should call on the expertise and resources available at USDA and other government agencies.

(3) A project is needed to study the fundamental biochemical processes that result in seed protein production. Such information could lead to significant advances in wheat breading technology and nutritional quality.

For instance, much practical information would become available if the special character of Atlas varieties, the primary source of genetic capability for efficient conversion of soil fertility to higher protein concentrations in wheat, were better understood.

(4) A program should be instituted to convince both individual farmers and national governments to adopt the new high protein wheat varieties as they become available for release. Information on the nutritional, economic, health, and social benefits to be derived from these new varieties needs to be developed for each target country. Information on relevant consumer habits and on the educational and marketing strategies necessary to achieve acceptance and cultivation of the new varieties should also be provided.

(5) Blended foods, such as CSM (corn-soy-milk) and Incaparina as well as fortified wheat flour, are products slowly gaining acceptance in developing nations. However, the many market failures by similar products indicates that AID should consider the establishment of a technological center to serve as a source of expertise in the processing of legumes and oilseeds into high protein flours and concentrates that can be incorporated into bread and bread-like products consumed in developing nations. The center should also provide the nutritional information, marketing assistance, consumer acceptance testing techniques, etc. that will insure the proper acceptance of these high-protein food products by consumers in target countries.

(6) AID should initiate an engineering, economic, and capital investment feasibility study in a group of neighboring countries willing to pool their efforts to achieve local production of lysine and other fortification nutrients. In this context, the local production and marketing of a broad spectrum micro-nutrient additive for individual family use can also be considered.

Governments often object to the use of scarce, hard currency to import such items as lysine, vitamins, etc. The capital investment and technological complexity required to construct a lysine production facility may require that two or more countries in a given

region cooperate in such a project. The recommended feasibility study could provide the incentive for such a development.

(7) Despite the major impact achieved by the "Green Revolution" in closing the gap in food grain requirements, P.L.480 wheat shipments will continue. It is, therfore, strongly recommended, in view of the nutrition benefits possible through lysine fortification of flour and wheat, that AID require fortification of all international wheat and flour shipments sent to such countries as India and Pakistan under PL-480, Title I.

REPORT OF TASK GROUP ON RICE

Rice is low in available utilizable protein and is a very major fraction of the diet of a large percentage of people in developing countries. Thus, there is no question that supplementation or breeding is a worthy item of attention.

Compared with wheat and maize, knowledge of genetics of rice protein is very limited. Much basic research needs to be carried out. However, this approach may nevertheless constitute the best access to the subsistence or near subsistence farmer. Present day rice breeding programs are directed toward securing the high yield potential of the new varieties by incorporating the following traits: (a) growth duration to best suit specific areas, (b) insect and disease resistance, (c) cold resistance where needed, (d) improved milling characteristics to reduce breakage of grains during milling, and (3) proper grain size, shape, and cooking behavior to meet demands of consumers in different areas. Fortification technology is still in the process of development. Although there are a number of problems remaining on the specific ways in which rice fortification can be carried out, it will be important to press ahead on all promising avenues.

The following recommendations are made:

1. Little is known about the impact on the protein content of rice of different practices, and the differences between the influence of specific environments, both in terms

of the context of the nutritional impact and the relative economics of different varieties. Experimental plot studies show substantial increases in protein content from added nitrogen fertilizer. But the meager "on the farm" samplings conducted to date do not show the same increases.

Extensive sampling of farm fields should be undertaken in several countries. Fields where traditional farming methods are used should by sampled as well as where improved practices are used. This comparison should include traditional varieties and the new improved plant type varieties.

2. Basic research is required into the genetics of protein which would lead to an ability to direct protein improvement research more efficiently than is now possible.

a. Breeding for increased protein content should be expanded. Present indications are that genetic differences in protein content exist. It may be possible to increase protein content from the 6 to 8 percent of existing varieties to possibly 8 to 10 percent and without reducing grain yields. The information now available justifies such an effort.

b. The major difficulty is in properly identifying genetic and environmental differences in protein content. Studies should be undertaken to further improve evaluation of protein as well as to develop rapid methods of analyzing for protein content.

3. There are vast areas of deep water, upland, and some rain-fed areas where the new technology cannot be carried out. Studies should be expanded to include improvement of deep water and upland varieties. Both offer opportunities.

4. Research is needed on the nutritional impact of human consumption of different varieties of rice and different protein levels. This should cover such things as biological utilization of protein and digestibility.

5. Fortification represents a new approach. Exploration of the various factors involved to determine whether this technique will prove feasible on a mass scale should be pursued vigorously. Among the various considerations to be taken into account are:

a. Fortification appears especially appropriate for urban areas where rice is processed in central locations and is amenable to treatment. However, more needs to be known about human response to fortification before large-scale program commitments are made.

b. For widely dispersed rural consumers, partly or wholly eating their own production, severe administrative and distributional problems remain to be overcome. However, extension of fortification to rural areas and exploration of techniques for such extension should certainly not be ruled out.

c. There is conflicting evidence concerning the limiting amino acids in rice protein. Some studies have shown that lysine may be the sole limiting amino acid; others indicate that lysine is first limiting and threonine second limiting. Since fortification of rice with lysine and theronine is considerably more expensive that fortification with lysine alone, it is important that studies be conducted to resolve this question.

RICE REPORT–APPENDIX

As an appendix to the committee report on rice, the committee chairman placed before the workshop two questions for general consideration:

1. *Research priorities:* For rice, in at least such areas as the Indian subcontinent, the problem of sheer yield has yet to be solved with anything like the degree of success achieved with wheat. For that reason, research priorities might be put in time as follows: Increased yield, enlargement of the genetic base, elimination of important barriers to consumer acceptability, and finally improvement of protein content

   Given that the breeding of rice should ideally be studied as a total system, we nevertheless need to consider closely whether the research community has the capacity to work on all these priorities at the same time.

2. *The problem of demand:* As we continue to develop and disseminate varieties that are both higher in protein and yield, supply may increase faster than demand. What implications does this have for the things we are breeding? If, for example, the Philippines have already arrived at the point where further rapid increases in yield are outpacing increases in domestic consumption, and are either going to continue to depress domestic price levels or have to be exported at a subsidy, perhaps we need to switch our attention to some other item entirely. And then, perhaps, we should assist a change in production patterns with some people diversifying out of the rice and going into other things. This general type of question deserves very serious consideration in the development of a breeding strategy for cereals.

REPORT OF TASK GROUP ON CORN, SORGHUM, MILLETT

Improvement of food quality of corn, sorghum, and millet will be dependent upon both the breeding of improved types and upon fortification. Work on techniques of fortification and the priority materials to be used should be continued and expanded. This committee, however, gave primary consideration to problems related to breeding. The following recommendations are made:

Corn

1. Primary emphasis should continue to be placed on improving yield. Given the end objective of producing a corn which is both high quality protein and highest yield, greater progress can be expected from efforts to improve yield of the high protein varieties than to attempt to improve protein in normal corn. (Genetic yield limitations in opaque-2 types appear to be related to kernel texture. Specific gravity techniques are available which, hopefully, will solve this problem.)

2. Corn breeding has advanced sufficiently to permit some immediate evaluation of the merits of improved types for the people of less developed countries. We recommend that AID establish a pilot project to evaluate the potential for opaque-2 corn. An important requirement is a sympathetic government in an area where adapted strains of opaque-2 corn are available. Colombia may be such an area. Possible consideration should be given to the evaluation of any nutritional advantage.

3. A research program should be established by ecological zones for the growing of opaque 2 corn. If certain ecological areas can be established, this will reduce the work

that has to go into each local area. The research conducted should include factors involved in adaptation, maintenance of yield, insect control, disease resistance, and adequate storage. Solutions to these problems are required for the development of a package of practices necessary for a satisfactory extension effort. When this stage of development has been reached, AID should give consideration to assistance or guidance of an extension effort.

4. The plant breeders have a great need for simple and rapid methods for the determination of lysine and tryptophan. Hundreds of thousands of samples need to be evaluated and current methods of analysis are inadequate for this volume of material. Further work on the development of analytical techniques should be undertaken.

5. An increased effort should be made toward the coordination of research work on high lysine corn and the establishment of a more efficient information exchange mechanism.

Sorghum and Millet

1. Additional support should be provided to plant breeders in support of work on digestibility, protein percentage, and amino acid composition.

In the case of sorghum, the breeding objectives will be to concentrate on yield, improvements in protein quality and quantity, and digestibility. The first pay-offs may come in the combination of higher yields and higher protein quantity. Significant improvements in quality and digestibility should occur in later stages.

In the case of millet, primary emphasis will be placed on yield and protein quality. Relative to other cereals, millet is already high in protein quantity, but this may be merely a reflection of the current low yield levels in millet.

Research should, where appropriate, also include attention to prevention of rancidity and the content of antioxidants. Vitamin E deficiencies may also be of importance in areas where sorghum and millets are staples. It should be noted that millet and sorghum are normally grown under very arid conditions that are not conducive to production of other crops that could supplement the diet. This increases the need for balanced nutritional quality.

2. With sorghum and millet, the need is even greater than with corn for simple and rapid analytical procedures for evaluation of lysine, tryptophan, threonine, and biological efficiency. The last item may be of greatest importance.

3. Fortification procedures should be developed suitable for subsistence farmers where the food grains normally do not enter into commercial channels. Elements of concern might include one or more of the following, amino acids, vitamins, and minerals.

4. Steps should be taken to increase, evaluate, and stabilize our reservoir of millet germ plasm. The value of the current world collection has been largely dissipated through inadequate and improper maintenance. New samples should be collected from India and Africa. A part of the needed effort on collection can be accomplished through correspondence if provision is made for subsequent increase and maintenance.

APPENDIX

WORKING PAPERS

(Each speaker was asked to provide a paper in rough form outlining his remarks for use of the other workshop participants.)

THE ECONOMICS OF PROTEIN STRATEGIES

Lyle P. Schertz
Foreign Economic Development Service
U.S. Department of Agriculture

This workshop's primary focus is on the technical dimensions of breeding and fortification programs designed to improve protein availabilities in the lower income countries (LIC). In contrast, the purpose of my paper is to sketch briefly an overview of the world protein problem and some of the major economic considerations of primary importance to these programs.

Sources and Uses of Protein

Two numbers dramatically depict the protein problem of the developing nations. (1) Two-thirds of the world, the poor countries, command only one-half of the world's protein and most of that is cereal protein (Table 1), and (2) the billion people in the developed countries use practically as much cereals as feed to produce animal protein as the two billion people of developing countries use directly as food (Figure 1 P. A-3).

Protein content of diets varies greatly among regions, nations, regions within countries, families, and among family members. This variability is a fundamental phenomenon which programs of plant breeding and fortification must take into account. It argues for great flexibility in program design.

The Role of Income

The fundamental situation is that large numbers of people in the developing countries do not have the incomes to command the food which would give them adequate protein in their diets. This basic phenomenon overhangs all efforts to bring about nutrition improvements. And, this is the basic reason, barring a miracle, why nutrition improvement must be viewed as a long-term process.

But, to argue that income is a primary explainer of changes in nutrition does not suggest nutritional improvement can be accomplished quickly through income growth. The outlook of income growth is such that great dependence of staple foods will continue, and in turn protein deficiencies will continue for many years. Consumption surveys amply indicate that limited incomes will not permit commodities such as sugar, meats, oils, fruits, and vegetables to occupy a major role in the diets of a large segment of many populaces.

Patrick Francois, for example, demonstrated in the October 1969 FAO Nutrition Newsletter that the potential effect of income in relieving protein deficiencies is slower than usually realized. For example, for a selected country, growth in per capita real in income over a 13-year period of 1.7 percent per year was assumed. This meant that per capita

TABLE 1: TOTAL PROTEIN SUPPLIED BY FOOD GROUPS - 1959-61 AVERAGE

Subregion	Population 1959-61	Wheat	Rice	Other Cereals	Cereal Total	Pulses & Nuts	Animal	Other	Total Protein
	Million	- - - -	- - - -	- - - -	*Million Tons*	- - - -	- - - -	- - - -	- - - -
DIET ADEQUATE COUNTRIES: [1]	1,089	8.6	1.1	2.8	12.4	1.9	15.4	3.2	33.0
DIET DEFICIT COUNTRIES:									
Latin America	84	.3	.1	.3	.7	.2	.6	.2	1.7
Africa	242	.6	.2	1.9	2.8	.7	1.0	.9	5.3
Communist Asia	713	2.1	3.9	2.4	8.4	1.8	.8	1.4	12.4
India	432	1.2	2.0	1.8	5.0	2.3	1.1	.4	8.8
Other Asia	452	1.8	2.7	.7	5.2	1.0	1.5	.8	8.6
Subtotal	1,923	6.1	8.9	7.2	22.1	6.0	5.0	3.6	36.7
TOTAL WORLD	3,012	14.6	10.0	9.9	34.5	7.9	20.5	6.9	69.8

[1] Adequate diet countries include those normally grouped as developed countries plus Mexico, Brazil, Argentina, Uruguay and Southern Africa. Other countries are grouped in diet deficit category.

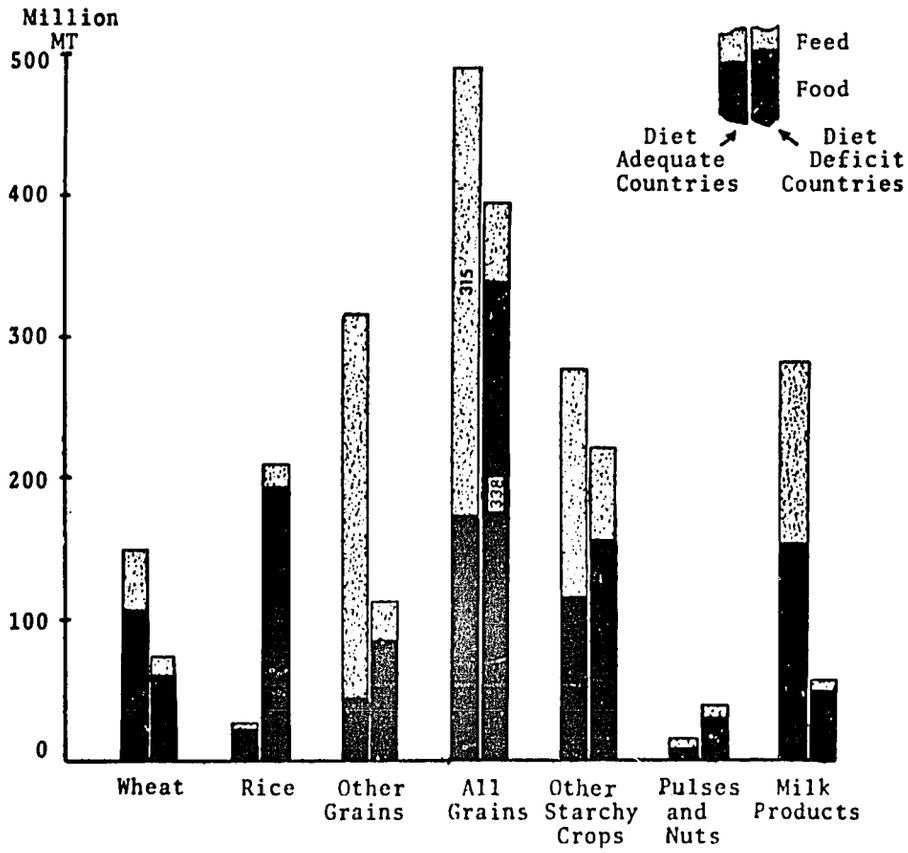
Source: Derived from Quentin M. West, "The Quantitative Role of Cereals as Supplies of Dietary Protein," *Protein: Enriched Cereal Foods for World Needs,* Max Milner, Ed. American Association of Cereal Chemists, 1969.

rural incomes would increase only from $52 to $65. In turn, per capita protein consumption would increase less than 5 percent. Animal protein would increase 23 percent, but less than two grams in the 13-year period. Additional calculations by Francois for the same country showed that in 23 years income can reduce the number of people "... whose protein status is unstaisfactory by only half," although in this case the percentage of the population with deficient diets dropped from 50 to 16 percent.

Also, economic growth can improve national nutrition averages, but at the same time make the low income people worse off. The reason for this potential whiplash on the poor is that as people's incomes rise they desire more animal products and bid grain away from the bowls of the poor for use as livestock feed. These prospective developments suggest the need for continued attention to programs which provide food to vulnerable income groups.

FIGURE 1: UTILIZATION OF AGRICULTURAL PRODUCTS FOR FOOD & FEED, 1959-61 AVERAGE

Diet Adequate and Diet Deficit Countries1/



1/Adequate diet countries indicate those normally grouped as developed countries, plus Mexico, Brazil, Argentina, Uruguay, and Southern Africa. Other countries are grouped in diet deficit category.

Source: "The World Food Budget 1970," FAER No. 19, ERS, USDA, Table 36.

It is because of the limited potential for increased incomes to solve the protein problem that considerations of supply–fortification to increase utilizable protein and plant breeding–take on increased urgency. One important aspect of fortification and variety improvement is that they make possible the availability of improved nutrition at lower prices. In this way a given amount of income can buy more nutrition.

Developmental Costs

Three of the more obvious questions about fortification and high protein variety programs are–Who pays? Who benefits? By how much?

Costs are of two types–(1) development and (2) implementing.

While substantial government funds are supporting the development of high protein cereal varieties, there has been little support for food legume improvement even though it has long been recognized that these corps occupy a strategic role in diet improvement. Also, government funds do not significantly support major research on the synthesis of amino acids even though the costs of tryptophan and threonine remain important barriers to their use in fortifying cereals.

The need for more research goes beyond basic research. Do we know enough about fortifying rice with amino acids so that the added nutrients will not be lost when cooked with large amounts of water? What is the stability of lysine introduced in a wheat mixture before grinding into atta? Private companies will work in these areas. But, are the risks sufficiently small so that private companies will devote substantial resources to this type of research? And, will they ask the same questions, disclose the same information, and do it as quickly as it needs to be done?

Implementing Costs

One great attraction of the variety improvement approach is the implicit anticipation that the product will compete with other farm crops in production decisions of farmers and move through the normal market system, and that consumers who need it will buy it.

This may all come to pass. But, it appears doubtful unless plant scientists develop cereal varieties with high yields having high protein content and unless varieties with comparable yields of low protein content are not available.

Diet improvement is hampered because nutritious foods are not inherently more attractive nor are their effects immediately obvious to the skeptic. Both producers and consumers tend to emphasize quantity rather than nutritive value in making decisions.

Needed, perhaps, are policies and programs which would favor the production and use of high protein varieties. This would help combat the "quantity syndrome." Advantages could be given to high protein varieties. Producers could be offered higher prices for high protein corn than for other corn. In turn, this corn could be resold below the other corn in order to stimulate its use. These approaches, of course, might be designed especially to stimulate the introduction of the varieties and then later adjusted to eliminate the advantages given to high protein varieties.

Unfortunately, quantity rather than nutritional value will continue to be the main criterion of producers, as well as most consumers in these countries. They cannot be expected to discard the quantity syndrome and substitute the sophistication in formulation of the U.S. feed manufacturers for many years to come. Quantity will remain an overriding consideration.

We know that to satisfy nutritional requirements with traditional methods will require income levels many times present levels. The fortification approach is much lower in cost, but it is still expensive in terms of either LIC resources or the willingness of developed countries to provide aid. However, the costs of several vitamins and minerals which are very deficient in many of the developing countries are extremely low. These cost levels, along with their known and accepted effects on health, cause one to ask why greater emphasis is not being given to mineral and vitamin fortification programs, especially in circumstances where it is not practical from a cost viewpoint to proceed with amino acid fortification.

Who Pays?

Someone must pay for fortification programs whether it be individual consumers, governments, or international assistance programs.

The willingness of an individual to pay for fortified products or high protein varieties depends on whether he thinks he is getting his money's worth. Unfortunately, especially in terms of the programs we are considering at this workshop, history supports the idea that man places major emphasis on palatability rather than nutrition.

One of the great virtues of fortification is that traditional foods are not changed in appearance or taste. Inability, for example, to distinguish fortified flour from unfortified flour has merit in terms of fitting existing consumption patterns. But, this virtue can also be a disadvantage in getting the consumer to pay a slightly higher price for a fortified product which is undistinguishable from an available unfortified product.

In some circumstances it may be possible to preempt the choise of consumers and thereby get them to pay the costs. For instance, governments might require that all flour be fortified. But, one must be careful not to be deceived as to how much progress such an approach really means in the context of the marketing systems and consumption patterns of the developing countries. For example, fortification programs of flour and atta were hailed by the Government of India as tremendous steps forward. They were especially important in introducing the concept of fortification. But, in terms of the cereal consumption of India, only a small proportion can possibly be involved in the near future.

In East Pakistan, only 10 to 20 percent of the rice produced enters what we would consider marketing channels. Most is consumed in villages in the areas where produced. Thus, the potential for preempting the choices of consumers should be seriously considered. But, we should not be overly optimistic as to the effect of this approach.

In the final analysis, we will likely find that governments will need to consider whether to carry the costs of fortification. Therefore, approaches will be needed which direct cereals to the vulnerable target groups. The fewer that receive the improved foods that

do not need these foods, the lower the real costs to society in reaching those that do need better nutrition.

Some countries have programs specially designed to make food available to lower income people. For example, several countries have school lunch programs. Others have ration shops and fair price shops which are designed to provide food for lower income disadvantaged groups of people. These institutional arrangements, along with price policies, represent important opportunities.

While the quantities have decreased somewhat, large amounts of cereals still move to the developing countries on concessional terms. Some of these cereals go to people with adequate diets, but significant amounts reach low income people with inadequate diets. Therefore, fortification of these products has very important potentials. For instance, given the cereal protein, vitamin, and mineral deficiencies of East Pakistan, shouldn't Japan be sending fortified rice to East Pakistan? And, shouldn't the United States be sending fortified wheat?

The Payoffs

We all agree that there is little question about the merits of adequate nutrition. In many respects, the benefits are self-evident as they are for better education, housing, and clothing. But, in a larger sense, do we agree that nutrition is a priority area? Resources are scarce. There are not enough resources to do all things–nutrition, education, housing, clothing–well.

The United States can afford to establish a goal of adequate nutrition without knowing the economic benefits. Resources are more abundant. The tradeoffs are in terms of guns, bullets, and farm subsidies. In the U.S. context, it really does not matter all that much if improved nutrition brought about by the food programs leads to merely greater consumption, or if it means increased productivity of a human resource and a saving of social expenditures in terms of medical facilities and like–in short, an investment.

The case in the lower income countries is greatly different, however, because of resource availability. Programs require a much greater cost benefit ratio to earn consideration. Problems in fulfilling goals for education in many of the countries are instructive for us working in nutrition. Many LIC's imitated the United States in establishing goals of education for all children. But, resources are simply not adequate to meet these goals in many countries. And, in turn, these objectives are being scaled down drastically.

In the final analysis, the true indication of the priority placed on nutrition will be the allocation of resources to this problem relative to the resources devoted to the other problems. But, for realistic decisions to be made, we need to know what contribution nutrition improvement can make to the improvement goals of economic growth and greater participation in the benefits of this growth. Can we say that improved nutrition will move a population from widespread lethargy to greater productivity? Or are the benefits more modest? Do we know?

In many cases we simply do not know the payoffs from nutrition, especially in terms of the contribution of improved quality and quantity of protein. But, effective work on the economics of protein in these countries will require more sharply focused nutrition research on problems relevant to them. For example, much more needs to be known on such important areas as the effect of calorie intake levels on the relationships between protein intake and physical growth.

Those with responsibility in the nutrition area need to develop the best information possible in objectively measuring human, economic, and social dimensions of these activities. To do otherwise will involve running the risk that decisionmakers will select other activities. And, none of us will be able to show them that they have selected the wrong ones.

BRIEF OVERVIEW OF PLANT BREEDING

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I have interpreted my assignment as involving several distinct, but closely related subtopics: (1) a brief overview of plant breeding; (2) the effects of agronomic practices on chemical composition; and (3) an organizational pattern that will facilitate an improvement in the dietary characteristics of cereals. Because of time limitations I shall confine myself to broad generalizations, recognizing that these may be inadequate in specific situations but may be useful in providing a general framework for more detailed discussions.

All of the cultivated crop species possess a wide range of genetic variability and, in the hands of man, have been modified to fit a wide range of ecological conditions and to serve a wide array of specialized uses. On the basis of this knowledge and experience, it is commonly assumed, given suitable criteria for evaluation and the necessary funds, time, and facilities, any crop may be modified to satisfy some specific objective.

If genetic modification, however, is to be considered from a practical rather than an academic viewpoint, affirmative answers must be available to two questions: Is modification feasible? Is it productive? I am using the term 'feasible' in a very broad sense to include not only genetic potential but also the availability of techniques for handling large numbers of samples as well as the related problems of agronomic acceptability and economic adequacy. I am using the term 'productive' in a more limited sense, to include the cost required to effect the desired change compared with other alternatives capable of achieving the same desired final objective.

An illustration may clarify the use of the term productive. Niacin is one of the vitamins which is deficient in corn. A diet having a high maize base may lead to the vitamin deficiency condition known as pellagra. This condition can be overcome by (1) inclusion of high quality protein in the diet or by an increased level of nicotinic acid amide or increased levels of tryptophan or (2) by developing new maize types with a higher concentration of niacin.

Studies by numerous workers have shown that niacin content is under genetic control. Recessive types such as 'sugary' or 'dull' are consistently higher in niacin than their normal counterparts. Within normal phenotypes, flint or dent, niacin content is inherited as a typical quantitative trait. In experiments reported from Tennessee, strains were developed having niacin contents as high as 70 micrograms per gram. Approximately one-quarter pound of such material would satisfy the daily niacin requirement and this value is well below the per capita daily consumption in heavy maize consuming countries.

The option is available, therefore, of increasing niacin through breeding or through some form of dietary supplementation. The breeding approach is the less feasible of the two alternatives. Increased niacin percentage is conditioned by multiple factors which are recessive in their expression. Experience indicates that multiple factors are difficult to transfer by conventional methods. If the commercial product is to be a hybrid, improved niacin content must be introduced separately into each of the component lines or populations. Incorporation would require several plant generations and the analysis of hundreds of samples. The development of high niacin types, therefore, is genetically feasible but would not satisfy the requirement of 'productivity' as I am using the term.

Of the dietary components required in larger quantities, protein improvement would appear to have the highest element of productivity. Solution of this problem, however, is neither straightforward or simple. For convenience in discussion I shall distinguish between protein quantity and protein quality.

Protein quantity has been known to be under genetic control since the classic 'high' and 'low' selection experiments conducted at Illinois through the period 1898 to 1970. In brief, these experiments have shown that protein percentage can be moved from the initial value of about 10 percent to high of approximately 20 percent and a low of less than 5 percent. These changes have been accompanied by equally striking changes in protein composition. The low protein material is characterized by the almost complete absence of the alcohol soluble fraction 'zein' which is lacking in both lysine and tryptophan. The protein produced, therefore, is of better quanlity than normal. Conversely, in the high protein series there is a marked increase in zein with a corresponding decrease in quality.

Environmental conditions also have a marked effect on protein content. It has long been known that there is a general inverse relation between yield and protein within the cereals. Low yields tend to be associated with higher protein levels while higher yields tend to be characterized by lower protein. Any stress condition which influences yield may be expected to have an effect on the protein content of the grain. Since protein percentage may be influenced by either genetic or environmental factors, a nitrogen analysis has little predictive value. It does serve a useful purpose, however, as a preliminary screening technique.

I mentioned the general inverse relation between yield and protein percentage. This association requires some clarification. Early information on this relation was accumulated prior to use of nitrogenous fertilizers. Under such conditions the nitrogen available for plant growth was determined by the native soil fertility and by the cropping system used. This fixed amount of nitrogen could then be utilized for growth and protein content of the grain to a degree determined by other environmental variables.

Under the present technology, varying amounts of nitrogenous fertilizers are used. The effect of such fertilization will depend on the characteristics of the plant and on time of application. If fertilization practices are such as to maximize yield, then protein percentage, of a given genotype, may remain relatively constant or actually decrease. Protein content may show no important increase except under conditions of luxury consumption. With current emphasis on yield, types with a higher capacity to store nitrogen may do little more than maintain current protein levels.

Having identified certain strains as above average in protein, one must then establish first the degree of environmental stability and second a genetic basis, if such exists. Environmental stability can be readily explored by regrowing the items of potential interest under a range of environmental conditions; tests repeated over locations or years, involving a range of soil types or fertility levels.

If the evaluation procedure stops with the identification of high protein lines, such lines may have limited value; a value determined by their agronomic capabilities and areas of adaptation. If a broader purpose is to be served additional information is required. This information involves the genetic capability of a given type to transmit the high protein characteristic to some realistic fraction of its biparental progeny. Significant differences are to be expected among 'high protein' lines in their capacity to function as desirable parents. With the identification of such desirable material the breeder, given time, facilities, and funds, may recombine the desired protein characteristics with other genetic traits which make for acceptable yield levels and consumer acceptance. The whole operation, from the beginning of screening, through the various evaluation stages and the final development of an acceptable product will normally require at least ten generations, adequate financial resources for the field operations, and a well equipped and staffed laboratory for the nitrogen and amino acid determinations.

Some of the operations outlined can best be done in the United States, possibly others in suitably located regional centers, but some work must be done in developing nations by local staff. There is a current impression that all of the necessary research can be done at one center with the final product directly useful on a world-wide basis. The use of the short-statured wheats from CIMMYT, so widely used in India, Pakistan, and Turkey, are cited as supporting the idea of concentrated research with a world-wide utility. The fact is overlooked that these types of spring wheat may be a special case; winter wheat, rice, sorghum and maize do not appear to follow this pattern. The rice varieties developed at the Philippine International Rice Research Institute are generally poorly suited to West Africa, the maize varieties of lowland and highland tropical areas cannot be interchanged, and neither type is productive when shifted any great distance either north or south. Many tropical sorghums will not flower in the United States and so forth. The full reasons for these specificities are not known; in some cases day length response is involved, in others, disease susceptibility is a factor, and temperature response is certainly involved. Our current knowledge of plant physiology and the influence of various aspects of environment is not sufficiently detailed to permit of a realistic evaluation of adaptation. Until such information becomes available adaptation must be evaluated empirically. Unadapted low-yielding varieties will not be acceptable even though they may be high in protein.

Until we are more knowledgeable concerning the factors influencing adaptation, any plans to aid developing countries in improving the protein level of their diets must recognize the need for both a U.S. and a local effort. High protein materials identified in a U.S.-based program are unlikely to be directly useful over a wide range of ecological conditions. One of the main functions of the U.S.-based program will be to identify superior materials which will be useful as breeding stocks. These elite high-protein stocks must still be crossed with appropriate recipient stocks from which regional or local breeders may then select adapted types which will combine an increased protein level with the other

traits which make for local acceptance, adequate yield levels, resistance to the locally important pests, and consumer acceptability.

If the foregoing assumptions are valid, a program of assistance to developing countries might well involve three different segments: (1) a U.S.-based operation responsible for screening and establishing genetic potential for high protein; (2) a regional program for the production of segregating populations and screening for protein and adaptation including disease and insect resistance and for consumer acceptability; and (3) the involvement of local country programs to perform the final evaluations for yield and production practices of local importance. Procedural details may vary among crops so we shall consider only general requirements.

1. The current AID-supported wheat program at Lincoln, Nebraska, will serve as an illustration of a satisfactory U.S.-based operation.

2. The second requirement involves one or more regional or satellite stations. Such stations will be selected to represent broad ecological zones. The staff for such a center must involve several skills; genetic and breeding, chemistry, agronomy, pathology, and entomology. The function of the center would involve choosing suitable recipient varieties, combining these with selected high protein parents followed by a detailed study of the segregating progeny. Priorities would be established on the basis of requirements of the area. It seems likely, however, that the first selective screening would be based on vigor and adaptation. Survivors would then be screened for protein percentage, insect and disease resistance, or other traits of regional importance. Nitrogen analyses may be the most demanding of these required operations. The facility must be geared to handle large numbers of analyses in a short period of time. Depending on the characteristic of the crop and the local cropping pattern the interval between harvest and planting may be as short as one or two months. Having identified potentially useful material we are ready for step three under this idealized program.

3. The potentially useful material is then supplied to developing countries for the final stages of testing. This testing should include not only variety evaluation but also aspects of crop management that may influence field performance. These requirements presume an adequate staff and facilities to make the final judgements on varieties to be released and to handle the details of increase and distribution.

Patterns of organization other than the one just outlined may be developed. The essential requirement is adequate provision for the three stages of development: identification of suitable high protein parents, a breeding and evaluation program to combine increased protein levels with other attributes of regional importance, and the detailed evaluation and production studies together with seed increase and distribution. Without provision for all three stages, any impact on developing countries will be minimal.

BRIEF OVERVIEW OF FORTIFICATION

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You have been given a detailed review of the subject in the folders that you have and I would like to broaden the discussion a little bit. I want to discuss three parts of this subject: 1) the nature of the protein problem; 2) the nature of fortification; and 3) possible interactions between fortification and breeding.

The Protein Problem:

We have been very much prone to consider the protein problem in terms of people who show it first, namely, the so-called vulnerable groups–the infants and pregnant and nursing women. And very often we have directed our solutions to these people. I would like to raise the question that when we do this – and I am not discounting the importance of doing this – but when we do this alone, and particularly when we do this conceptually, we are more likely treating the symptoms than the problem itself. I would like to suggest that when you have a problem showing itself among the vulnerable groups this is a reflection of a more serious problem affecting the entire population.

Let me give you an example in the case of India. In the last ten years, as a result of very great efforts of the plant breeders and the farmers in India, the cereal availability per capita has increased from 135 kilograms to 150 kilograms per capita, mostly in the form of wheat. At the same time, the per capita availability of legumes has decreased from 25 kilograms per year to 17. Since the Indian food economy depends on balance among cereals and legumes and a little milk, there has been a deterioration in this balance between the protein calorie sources. It shows up first in the women and the children, but to say that this is solely the problem is to miss the very basic problem that creates this situation. So, while sometimes we have to talk about the vulnerable groups, we must not forget the basis of the problem.

The second point I would make on the nature of the problem concerns the relationship between proteins and calories which is different than that of vitamins and calories. You can get into as much trouble by vitamin deficiency as you can by protein deficiency. But that isn't the issue. The issue is that you cannot talk about calories without talking about protein at the same time. The economy is intermixed and how you decide to get your proteins determines how many calories you have available. This does not necessarily follow for vitamins. In the United States we have 1750 pounds of grains available per person per year. Of that we eat 150 pounds and feed 1600 pounds to animals. Now, that is our choice, but we have used a great amount of grain to put through animals to get the kind of food we want. Had we chosen to do it another way, we might have had a lot more calories or might have decided to make more calories available to others.

So the calorie supply of a country is based in part on the decision on how you get the protein. Therefore, you can not talk about a calorie problem without talking about protein. You can not talk about a protein problem without talking about calories. This is a basic issue of total food supply. And this is why we talk about protein, rather than vitamins, or other micronutrients.

The third point is the point that Dr. Schertz made very clearly, the relationship between food problems and income. At this time in history, on a worldwide basis, there is no shortage of food and there is no shortage of protein. The problem is that those people who have a shortage of either total food or proteins do not have the income, nor does their country have the foreign exchange to buy these proteins. So it is a problem of getting proteins and food at a low cost.

Let's talk about solutions. The obvious solution is to raise the income. That is going to take a long time, and there is no guarantee that the first increment of income is going to be used for food. There was a very interesting paper by Francois of FAO in which he considered the projections in a rice eating country of incerased income and pointed out that in a society where there is no intervention, the chances of the protein problem and the general malnutrition problem being solved simply by increased income were very low indeed. And so it seems that the only solution that is practical within any kind of a limited time span is to intervene in the quality of the food supply in such a way that the food can be improved, not by going from a per capita income of $100 to a per capita income of $700 to $800 per person per year, which is what Max Millikan said it would take to cure malnutrition, but perhaps with a 10 percent increment of the existing per capita income.

The Nature of Fortification:

A very small number of decision makers are required to put a fortification program into effect in any given country.

This type of program started out in this country as an effort to replace lost nutrients in wheat flour. When flour is milled, certain of the vitamins are lost and therefore the fortification was really enrichment. It was primarily to bring back the B vitamins that had been lost in the process of milling. But as the concept developed, it became a tool for introduction of any kind of a food ingredient, and there was no necessarily logical relationship between the carrier and the additives – for example, iodine in salt or flourides in water, or adding vitamin A to certain flours because flour was a carrier. I think this is one of the basic principles of fortification.

The logic of fortification is not that of the plant or animal science. It is the logic of nutrition. One does not have to consider what logically can you add to a plant on the basis of its genetic capabilities, but you can talk about a logic of nutrition and use the plant or the animal as a carrier for that nutrition. Why can we talk about it? Because there has been an explosive increase in our knowledge of food technology and nutrition in the last century which in a large sense allows us to know that certain food ingredients are required for minimal healthy existence. I don't want to pretend that we know everything that is necessary, but neither would it be fair to say that there isn't a lot of things that we do know about necessary ingredients.

Secondly, we have made progress in the production of these micronutrients, principally the vitamins and now the amino acids. They are available at reasonable cost and they will be available at even more reasonable cost as demand increases. This has given us this extra capability of using nutritional logic with whatever can be the best carrier.

Now let's talk about protein fortification. I would like first to talk about the relationship between protein quality and quantity. I think that this is a very important point that keeps being stressed to me time and again by my associate Dr. Rosenfield. You just can't talk about quality of protein without talking about quantity; they are interrelated. The protein quantity in a food material as determined by chemical analysis doesn't count. What counts is the available protein in that material which is some fraction of the protein quantity multiplied by the digestability, the quality, and a number of other things.

Let me just read you some figures taken from Hegsted and Jansen. According to Hegsted, the percentage of utilizable protein in white wheat flour is 3.2 percent. When you add 0.2 of a percent of lysine to that wheat four, the percentage of utilizable protein is 5.3 percent. So you have increased the quantity of protein available to the person; this is all that counts, because a person needs a certain amount of available protein. According to Jansen, the utilizable protein in white bread is 7.3 percent; add .3 lysine, it becomes 10 percent. In corn meal, it is 3 percent originally; add tryptophan to the lysine and it becomes 5.1 percent. In rice, it is 4.5 percent for a Thai variety; add lysine and threonine and it becomes 7.6 percent. You have increases up to 60 percent in available protein when their amino acid deficiencies are eliminated.

Increasing the amount of available protein in a foodstuff by completing its amino acid pattern is the most efficient way of providing more utilizable protein. One of the elegant presentations of this was by our chairman Harold Wilcke at the Amino Acid Conference held a year ago in which he showed that 6 percent animal protein could complete the balance of protein in wheat with a surplus of most essential amino acids. Theoretically, amino acid supplementation is the most efficient of all, but it may not be the cheapest way because what will be cheapest in practice will depend on the relative cost of the essential amino acids and the other sources of amino acids, be they from animal sources or from soybeans, for example.

Now how do we envisage fortification? I think we have to talk about the possibilities and we have to talk about the limitations. I think we have to be cognizant of the very important point that Mr. Butterfield mentioned earlier, and that is that one major element of our thinking should be reaching the rural areas. It is easiest for wheat. The reason it is easiest to fortify wheat is that in any country where there is wheat milling the number of mills is a small and it is quite easy to control it. But it is also possible for rice and corn, and it is also possible in any of these in a rural context. A number of us just returned from Thailand where we saw one of the fortification tests going on in a Thai village where there was no money economy in rice but each person brought in his own rice to be milled by the village miller. While he was doing it, we were feeding in a fortification granule at a rate of 1 percent.

We are not limited to total fortification of rice, corn, or wheat. There are a number of interventions. I think the point was made by one of the early speakers that there is no panacea for any of these nutritional solutions and that many different things will have to be done. I would list some: Modern Bread in India is introducing a fortified product to a

number of consumers. This kind of consumer is increasing in terms of income. In other words people are aspiring to eat bread and therefore the lower income groups are moving up into bread as rapidly as they can. The same thing is happening in Brazil. Atta is being fortified in India. This reaches a large number of people. We had a very interesting discussion with the head of a cooperative in India – a dairy cooperative. Twice a day a member of the family – of each family – brings milk to a receiving station. So far they haven't been carrying anything home. But it would be very easy – and this affects several million people – to have some nutritional supplement returned home with them. This supplement could be designed to supplement with amino acids, vitamins, and minerals, the food that they are presently eating, and this would be a delivery system for a rural area. Fortified pasta, which is soy plus wheat or corn is now being sold in several countries. This is a means of fortification. In the United States, we have looked at many types of engineered foods – cake, fortified pasta. One company is now putting lysine in jelly as a means of getting lysine to bread because jelly is eaten with bread. Another company is considering the fortification of all bread and flour in certain areas where there is a need. We are thinking of fortifying textured soy with methionine as a means of making that kind of soy equivalent to meat. There are many ways of reaching people by fortification whether in a urban or rural context.

Figure 1 shows the increment of increase in effective protein content when amino acids are added to the cereals. You have there wheat, flour, waterbread, corn meal, and rice.

EFFECT OF AMINO ACIDS ON
NUTRITIVE VALUE OF CEREAL PROTEIN
(Percent Utilizable Protein)

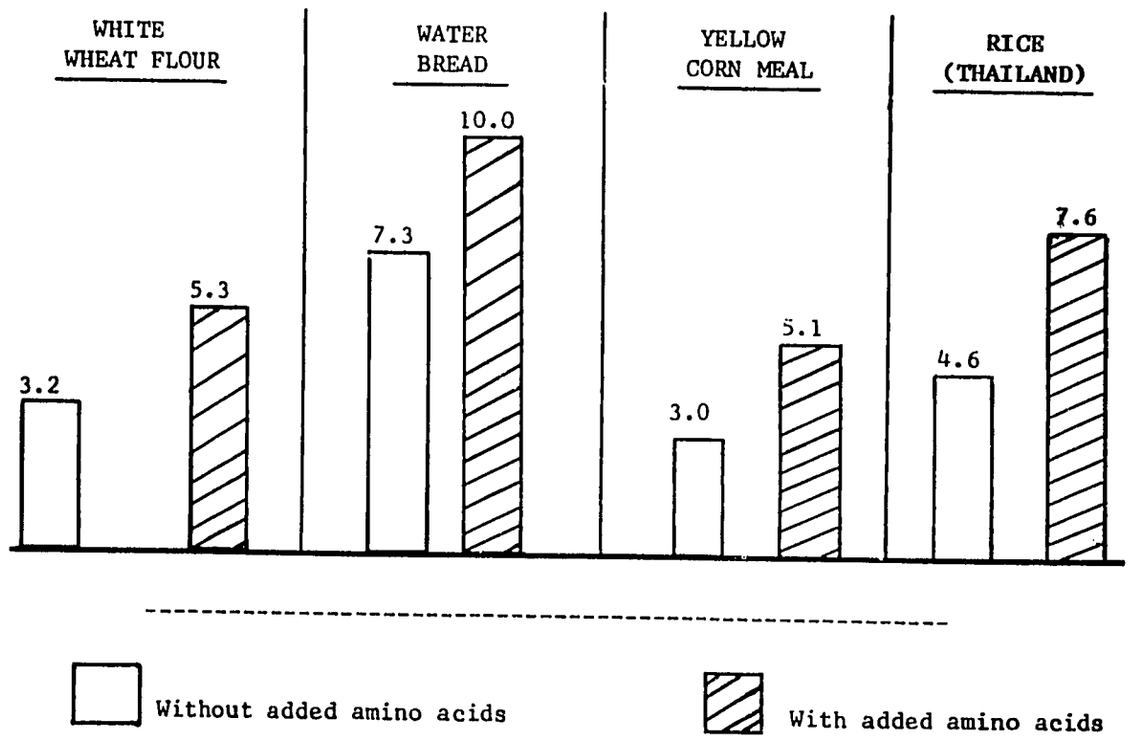

Figure 1

Figure 2 shows the relative cost in terms of the cost of the cereal to get an increase in the effective protein content. Wheat fortification in Tunisia would cost 3.5 percent of the cost of the wheat. That is the simplest because all you add is lysine. To get a 70 percent increase in the effective protein content of corn in Guatemala would cost 15 percent, because of the current high cost of tryptophan. And to get a 60 percent increase in the protein impact of rice would cost 13 percent. That high number results from the higher cost of theronine.

Who pays for it? Obviously for the poorest people there is going to have to be some sort of a subsidy.

When you intervene in the food to improve its protein content, you can do all kinds of intervention. And certainly one would not want to add amino acids without balancing the food with respect to its vitamin and mineral content.

Finally, I would like to discuss the possible relationships of fortification proponents with breeding proponents. One relationship, which held for quite a long time, was no interaction. This is a characteristic of the state of affairs for the history of fortification for most of its time. The breeders and economists concentrated on calories and on yield of calories as grain. In this respect, this is an historic meeting for we are witnessing the beginnings of interaction between breeding and fortification experts.

RELATIVE COST OF FORTIFICATION

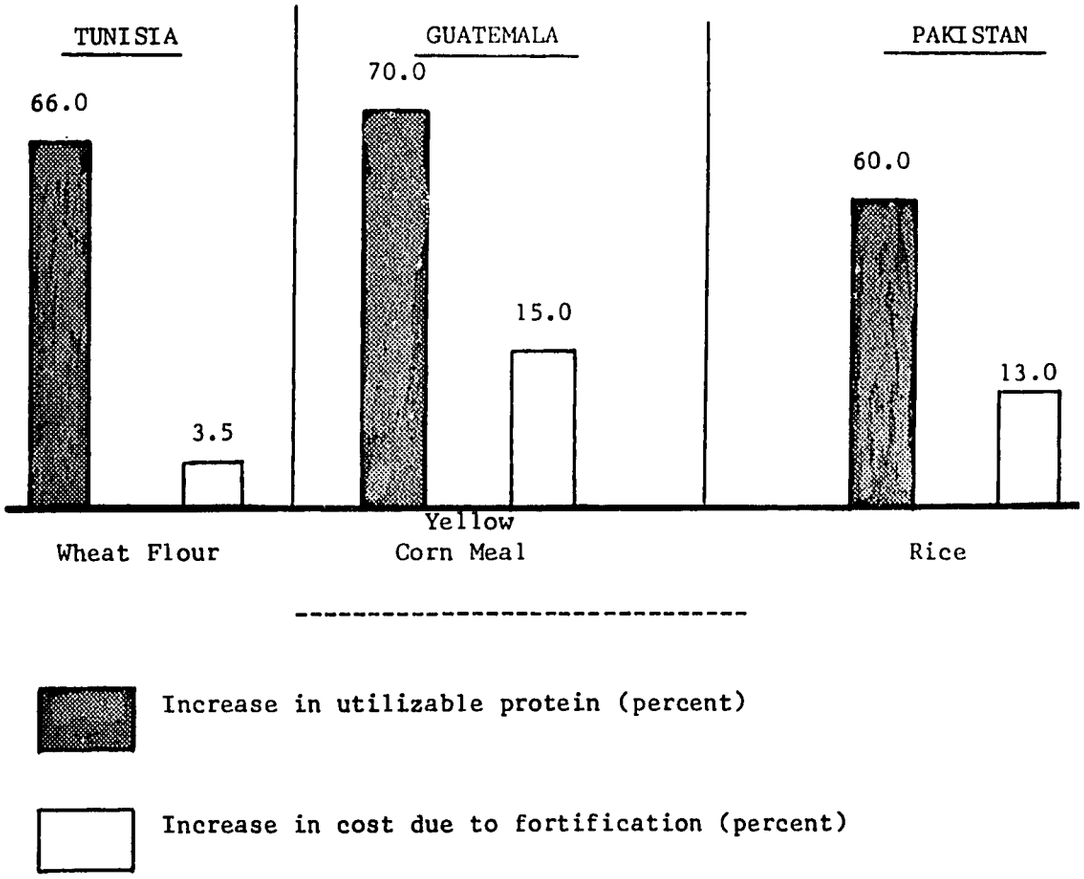

Figure 2

The second state of affairs, which I think started with the breakthrough in corn and which has proliferated with other crops, is that one can consider either fortification or breeding as optional choices. Perhaps there is a little bit of a competition between the breeder and fortifier as to who gets there first. There isn't anything wrong with competition; one ought to seek the best solution. But I think we ought to be sure that when we are fostering competition each discipline is undertaking what it is most competent to do. Otherwise there is a waste of talent and money and also of misrepresentation to the public as to what really can be achieved by either discipline.

The third possibility which hasn't yet started, but which may start today, is constructive cooperation in which each kind of approach considers its strong points. The breeders' strong point is that they can get a high yield of cereals, among others. One of their opportunities is to try to get a high yield of protein crops. And I think that the breeders will agree that they have the ultimate responsibility of providing enough calories for an ever-increasing population. This is number one and this is what they have to do. And whatever else they do must be within the constraint of providing enough calories. If they provide better quality but fail on the calories, they will have lost the ball game.

What are the fortification strong points within the constraints of delivery systems? You can balance a food with largely nonagricultural materials: minerals, synthetic vitamins, and synthetic amino acids. You can adjust food ecology by using some foods as preferential carriers. If in a certain society there is a deficiency of vitamin A, you are not limited to the natural carriers of vitamin A, but you can develop a strategy for getting vitamin A to those people based on what is the most likely and most economic carrier. You can give the breeder a greater versatility and flexibility because you can meet him half way. Let's say he gets a corn with higher tryptophan but not quite as much lysine. He can add a little more lysine to that corn and complete the job. The breeder doesn't have to do the whole job nor does the fortifier have to do the whole job; each can do his share to reach the lowest cost mix. You can either let the breeder sacrifice quality for yield and broader genetic base or make up the deficiencies in another way such as fortification. If for example to get a higher yield, he has to grow a crop variety with a lower protein content, maybe this could be compensated. Or if you have to have a lower vitamin content, this could be compensated via vitamin fortification.

Someone made the crazy suggestion which I pass on to you – it might be better to allow the breeder to breed out nutrients. We are always talking about breeding in nutrients, but in view of some of the problems of insect and rodent infestations, it might turn out that somebody would consider it an advantage to reduce the nutrients in certain crops and put them back in later when they could be protected by proper packaging.

And so there is the possibility of an interaction between the breeder and the fortifier. I would hope that at this meeting we would adopt the third position, which is to try to adopt a joint strategy for a number of critical localities. And more importantly, perhaps we will be able to continue the dialogue that has started today.

PULSE PRODUCTION – STATUS AND POTENTIAL

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Legumes have been cultivated by man since probably the 8th millennium B. C., since he began to pass from a hunting and food gathering to a food producing way of life based on village communities. Remains of crops such as field peas and lentils have been found by excavators in the Fertile Crescent of Asia and of beans in Mexican caves.

The family Leguminosae is the second largest family of seed plants, containing some 600 genera with 13,000 species. Only a limited number are of economic importance as pulses or food legumes, those of which the seed in dry or green form are used for direct human consumption. Some ten or twelve crop species fall in this category. This includes ones of importance in the developed world, such as beans (*Phaseolus vulgaris*), peas (*Pisum* spp.), soybeans (*Glycine max.*) and peanuts or groundnuts (*Arachis hypogaea*) and a number of crops solely important in developing countries of the tropics and subtropics such as chickpeas (*Cicer arietinum*), pigeon peas (*Cajanus cajan*), mungbeans (*Phaseolus aureus*), urd beans (*Phaseolus mungo*), cowpeas (*Vigna subebsus*), lentils (*Lens esculenta*), broad beans (*Vicia faba*) and several others.

Vegetable sources supply some 71 pereent of human protein intake, according to FAO estimates. Out of this 71 percent, pulses, oilseeds, and nuts account for 13 percent, cereal grains account for 50 percent.

Total world acreage and production of the major food legume crops including soybeans and peanuts in comparison to wheat and rice is as follows:

	Area (000 hectares)	Production (000 metric tons)
Pulses	63,089	39,614
Soybeans	33,672	40,764
Peanuts	18,496	17,398
Total Legumes	115,257	97,776
Wheat	221,900	298,000
Rice (paddy)	128,800	275,900

(Data from 1968 Production Yearbook, FAO)

These statistics show the importance of food legumes acreage-wise, almost equal to rice, but their considerable lag, production-wise, caused largely by the pulse crops other than soybeans and peanuts grown principally in developing nations.

Need for increased production.

In the developed countries, legumes are now an almost insignificant part of the diet. There are no nutritional reasons for reversing the downward trend.

In developing countries, which are short of protein, the situation is different. Statistics and estimates show that, in large parts of the developing world, a consumption of legumes ranging from thirty to seventy grams per head daily appears to be possible. But even in countries where these daily per caput supplies are available, those groups of individuals needing the protein most, growing children and pregnant and nursing women, usually receive far less if any.

Statistics of supplies calculated on the basis of populations and estimated production are only just that, figures which are only as good as the source from which they come. They do not take into account fluctuations of availability to groups within the population, the quality of the protein, and the contribution of legume protein to nutritive and amino acid balance of the diet.

In countries where starchy roots and fruits such as cassava, yams, sweet potatoes, and bananas replace cereals as staple foods, legumes assume a much greater importance in providing the needed protein.

On the whole, there is little doubt that a considerable increase in food legume production can help fill the need for increased food grains in general as well as provide a great boost to the world's protein supply.

Yield of Protein of Different Crops[1]

Crop	Protein, kilograms per hectare
Rice	42.3
Sorghum	33.0
Maize	73.0
Sweet Potato	36.5
Chickpea	88.8
Cowpea	
Groundnut	113.4

[1]From Brock, J. F., and Autret, M., "Kwashiorkor in Africa," Rome, FAO, 1952 (Mineo). Figures based on African crops 1946-48.

Advantages of food legumes.

(1) Commonly grown, worldwide.

(2) High in total protein content, 18-25 percent.

(3) Good essential amino acid balance. Limited in sulfur amino acids, methionine and cystine, but high in lysine. Makes them particularly valuable as supplementary cereal diets.

(4) Commonly consumed at all economic levels. No problems of acceptance of new foods, reaching poor people with processed products, or overcoming religious taboos.

Present status.

Throughout history, legumes have not enjoyed the prestige of staple cereals. They have not enjoyed the attention in improvement programs because they did not rank high among income producing crops and were generally limited in use to the rural people whose needs were not considered very seriously by national governments or colonial powers.

There has been very scant worldwide interest in the improvement of these crops even in recent years. Only a few species have been of importance in the developed world from where generally the impetus of development has come.

In addition, they are difficult crops to grow well for a farmer and difficult to work with for a researcher because of the numerous hazards encountered during the growing season.

Until recently there have been only scattered, inconsistent research efforts in the developing world on these crops.

It would be quite erroneous and misleading to take too seriously the comparison of thirty years of research on wheat or corn with the unconnected reports on the improvement of the food legume crops.

Only in very recent years have food legumes begun to attract some attention as being important links in the world's food chain.

There is a great deal we do not know about these crops. It is impossible as yet to come up with a package of practices which will assure a farmer a good crop.

But we do know that a substantial increase in yield over what cultivators are now producing can be obtained, Yield trials in Iran with selections from local cultivators but with good management of irrigation, fertilizer, pest control, and proper plant populations have given yields as high as 400 percent of average farm yields.

Extensive germplasm collections of the major food legume crops have been assembled in recent years. Although they have been initially screened, they need to be thoroughly evaluated for a wide range of characters so that parents can be selected for use in crosses with wide genetic diversity for development of superior varieties. In general, the genetic

base of existing breeding programs on these crops has been much too narrow. From these collections, nine new and improved varieties of beans, cowpeas, mungbeans, and chickpeas were selected in Iran and recommended to the Government for release. In India, IARI released a variety of mungbeans -Pusa Baisakhi- which can produce some 1000 kg per hectare in a 70-75 day period from April to June, between harvest of wheat and sowing of summer monsoon crops, when normally no crops are produced.

Other research institutions in India as well as in several other countries are beginning to make use of these collections.

Legumes are extremely susceptible to a wide range of diseases. The causal organisms of many of these have never been identified even though the diseases have occurred for many years. For others the causes are known but no solutions have been found. In chickpeas, for example, the blight disease caused by a fungus, *Ascochyta rabiei,* has severely limited production in several countries of Asia, notably India and Pakistan. Until recently, the search for resistance was only limited to screening of local types under national conditions which yielded little in the way of worthwhile results. In the past few years, we have learned that there are several races of the fungus involved and that good genetic resistance occurs. It was identified in a variety from Israel. This resistant type is now being used by breeders as a parent in making crosses to incorporate the disease resistance into agronomically more attractive new varieties. Control of this disease alone could increase yields of the 3.5 to 4 million hectares of chickpeas in the Punjab area of India anywhere from 5 to 50 percent.

Insects cause great damage to legume crops, particularly during the hot, humid rainy season in the tropics. Although chemical controls are available for most insects, application of insecticides is not feasible for the peasant farmer for whom a simple knapsack sprayer is economically out of reach and technically too complicated. Resistance to insect attack must be found and incorporated in new varieties. Only a start has been made in this work but indications are that resistance can be found to several insects. Chickpea and lentil lines have been identified with resistance to bruchids, a group of pod and seed boring insects whose damage to various food legume crops has been estimated as high as 40 percent. Cowpea lines with considerable field tolerance to several leaf chewing insects such as flea beetles, leaf miners, and jassids have been found in preliminary field trials.

Little is known about bacterial interactions and competition under natural field conditions in tropical soils. A great deal of microbiological research is required before successful exploitation of the nitrogen fixation capability of legumes can be practiced as a soil fertility factor.

There is little doubt that food legume crops respond to good crop management practices such as proper land preparation, planting in rows, irrigation, weed control, insect control, fertilizer application, etc. What little information there is in the literature shows that improved management over present practices can make a sizable contribution towards better production.

The pulses are high protein crops. We know that they are generally high in lysine (with the exception of peanuts) and low in the sulfur amino acids. We know little of the possibility for improvement in the nutritive qualities. No large scale systematic screenings

of germplasm have been conducted to determine the genetic range in total protein or amino acids. A preliminary screening in India of some 1800 pigeon pea germplasm lines for protein content showed a range from 18 to 32 percent, which seems to indicate considerable improvement potential. To my knowledge, no breeding work has been or is being conducted anywhere towards improvement of total protein or of the limiting amino acids.

Flatus producing factors, toxins, and antimetabolites are of considerable importance in food legumes, but here again the information available is not sufficiently specific and no screening programs have been conducted to provide information necessary for improvement programs.

Main problems.

(1) To find answers to the numerous production problems, some of which I have just discussed, research must be undertaken to develop new varieties with high yield potential, resistant to diseases and insects, responsive to fertilizer and other management and input factors.

(2) To launch extension education programs to educate farmers to grow these crops with the same care and on the same basis as they now do cereal grains, the food legumes must be removed from their present status of second rate crops.

There are no serious adaptation problems. At least one food legume crop is grown commonly in each major protein deficient area and there is little need to try to introduce new crops in new areas where this may involve serious adaptability problems.

Greater consumption can be brought about simply by greater production. All programs to increase supplies of legumes must depend in the first place, not so much on devoting more land to their cultivation, as on achieving higher yields. Some government efforts may be required to guarantee the producer a worthwhile price and balance the demand and supply picture. There is little doubt that in countries where pulses are accepted and eaten as a common food such as India, Pakistan, and other Asian as well as Latin American countries, a much greater demand exists than supplies of present production can satisfy.

Food legumes as fortifying agents.

Food legumes, with the exception of soybeans and groundnuts, have not been widely used as components of fortified food. There are reports of chickpeas, pigeon peas, mungbeans, and others being used in research and pilot feeding programs of Indian institutions such as the Nutrition Institute in Hyderabad, the Home Science College in Coimbatore, and the Central Food Technology and Research Institute in Mysore.

One quarter of one percent lysine added to wheat flour increases its usable protein by one third. Chickpea, pigeon pea, mungbean, beans and other food legumes with lysine contents of about 5 to 7 percent of their protein should perform at least that well.

Corn and cowpea in a 50-50 ratio has been reported to improve the PER from 1.22 for 100 percent corn to 1.84.

Soybeans and soybean products have been widely used in fortification as well as in new food development programs.

Efforts to develop manufactured food legume products or utilize them in fortification programs should be continued and intensified. But as a primary priority much greater importance must be assigned to legumes prepared by ordinary household methods. It is in this form that their use can most easily be extended, particularly in rural areas of the developing world where the need is greatest.

Implication of HYV of food legumes on breeding and fortification of cereals.

In the foreseeable future there certainly does not appear to be a likely conflict between food legumes and cereals. Predominantly cereal eating peoples will remain so and will continue to eat legumes as a supplementary and complementary part of their diets. They will not likely ever become the principal component. Legumes are a part of the food grain chain and it will be a long time before complete sufficiency of food grain production is reached. Improvement in food legume production should not be regarded as a potential competition with cereals. At the present time in the major pulse producing countries of Asia, the high yielding varieties of cereals are causing a decrease in pulse acreage however, resulting in decreased production and per capita availability of the protein source of millions of people.

It is conceivable that high-yielding and high-quality varieties of cereals and pulses may make fortification no longer necessary, but even that time is far off.

Conclusions.

Food legumes or pulses are an essential part of the traditional diets of many if not most of the developing world's people. They are important because they are high-protein crops, with well-balanced essential amino acid complements. They are also important because they often provide the only high-protein part of the diet and together with the main cereal or starchy food they provide a reasonably balanced diet.

A great deal of research, basic and adaptive, of the same magnitude and intensity as has been devoted to wheat, maize, and rice in the past twenty years or so, is required to provide a possible breakthrough in production of these all-important nutritional crops.

I recommend to AID that it continue its interest in pulses and support the recommendations for expansion and acceleration of research to increase production of food legumes recently submitted by the Rockefeller Foundation to the heads of international assistance agencies.

MEETING PROTEIN AND AMINO ACID REQUIREMENTS OF MAN

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A. 1. Essential amino acid (EAA) requirements established by means of crystalline amino acids have been reported in milligrams per day:

EAA	Man[1]	Woman[2]	Boy[3]	Infant[4]
Isoleucine	700	450	1000	280
Leucine	1100	620	1500	810
Lysine	800	500	1600	1350
Methionine	1100	350	800	770
Cystine	-	200	-	600
Phenylalanine	1100	220	800	810
Threonine	500	305	1000	540
Tryptophan	250	157	120	200
Valine	800	650	900	850

[1]Rose, W.C. Highest observed requirement.

[2]Leverton et al. Mean value; 900 mg tyrosine.

[3]Nakagawa et al. Japanese, 9-12 years old.

[4]Calculated for 9 kg infant from data of Snyderman. Infant also needs 280 mg of histidine.

B. Adult Human Subjects

1. Lysine requirements (Clark et al., J. Nutr. 71, 229. 1960)
   Men, mean wt 75 kg: 400 to 1200 mg, mean 750 mg and 900 mg adequate for all under 90 kg
   Women, mean wt 61 kg: 300 to 750 mg, mean 550 mg
   Lysine requirements are related directly to body size and urinary creatinine.

2. Calories: adequate calories are essential for efficient utilization of protein.

3. Relative proportions among EAA

   Attention needs to be given to the combination of essential amino acids, the amounts and proportions, as well as individual amino acids. Nitrogen retention tends to improve as quantities of essential amino acids increase in the same proportion; but reduction in the amount of one EAA reduces the efficiency of utilization of the entire mixture.

4. Opaque-2 corn

When used as the principal source of protein, 300 g of *Opaque-2* corn met minimal requirements for maintenance of nitrogen equilibrium of healthy subjects weighing 70 kg or less; whereas 600 g of ordinary maize have been reported to be necessary. The 300 g of *Opaque-2* corn contained 1600 mg of lysine and 470 mg of tryptophan. Supplementation of 200 g of corn with lysine, tryptophan or methionine did not make it equivalent to 250 g of 0_2 corn although it should theoretically have done so. (Clark et al., A. J. Clin. Nutr. 20, 825, 1967). *Floury-2* corn is also of considerable interest.

5. Rice

Adult human subjects maintained positive nitrogen balance when they consumed 8.0 g of nitrogen (48 g protein) from 595 g of commercial long-grain rice whereas 6.0 g of nitrogen (36 g protein) from 450 g of rice were adequate for some but not all men weighing nearly 70 kg. Replacement of 15 or 30 percent of the nitrogen of rice by animal protein (chicken) did not significantly improve retention. It is estimated that 1600 mg of lysine, 600 mg of tryptophan, and 1680 mg of threonine supplied by 520 g of rice alone would meet minimal needs of men.

A high protein rice from the Bureau of Plant Industry of the Philippines containing almost twice as much nitrogen and at least 1.5 time as much lysine, tryptophan, and threonine as the standard variety, caused a distinct improvement in nitrogen retention since 480 g produced strongly positive nitrogen balances in all subjects.

The effect of genetic modification on certain essential amino acids in corn and rice is illustrated below:

Amino acid	Mg EAA Per Gram N				Mg EAA/100 Grams Cereal			
	Corn		Rice[1]		Corn		Rice	
	Normal	0_2	BB	BPI	Normal	0_2	BB	BPI
Isoleucine	290	215	310	280	425	400	370	750
Leucine	810	580	660	615	1200	1080	1620	820
Lysine	180	290	190	235	265	540	470	310
Methionine	120	110	110	225	170	205	280	300
Cystine	80	90	110	140	120	170	270	180
Threonine	250	240	260	280	370	440	640	370
Tryptophan	40	90	80	85	60	160	190	115

[1]Bluebonnet (BB) and BPI-76-1 grown in the Philippines in 1969. BB 1.33% N, BPI 2.44% N.

C. Preschool children

1. Infants and small children comprise 14 percent of the world population, school children 24 percent and persons over fifteen years of age 62 percent. Data on protein requirements of preschool children are limited. The following allowances have been proposed:

Source	Age	Wt.	Protein		Kcal	Cal-cium	Iron	Vit. A	Thia-mine	Ribo-flavin	Nia-cin
	yr	kg	g/kg	g/day		mg	mg	IU	mg	mg	mg
FAO('65)	1-3	12	.88±.16	11							
	4.6	18	.81±.16	18		400-500		(1000)	.7	.9	11.2
NRC('68)	3-4	16	1.9	30							
	4-6	19	1.6	30		800	10	2500	.8	.9	11.0
Phil.('70)[1]	1-3	12	(2.2)	26	1300						
	4-6	17	(1.9)	32	1600	500	7	2500	.8	.8	11.0

[1]For protein based on FAO, corrected for 63 percent NPU found in the Philippine diet; energy derived from protein 6-7 percent for children one to nine years but 8 percent was considered desirable.

Taking into consideration the protein allowances and the protein content of certain cereals, the following estimates may be made:

2. Quantities of certain proteins required to supply 20 g Protein[1] for 4-6 year old child, and EAA present

Source	Protein	For 20 g protein	Lys-ine	Methio-nine	Cys-tine	Threo-nine	Tryp-tophan
	%	g	mg	mg	mg	mg	mg
Corn, whole ground	9.2	200	530	350	240	730	110
Corn, degermed	7.9	240	545	350	240	760	110
Corn, *Opaque-2*	11.6	160	860	330	270	700	250
Rice, white	7.6	240	750	720	430	890	280
Rice, high-protein[2]	14.5	125	600	360	350	810	240
Wheat, whole	13.3	146	530	300	430	560	240
Wheat flour, white	10.5	173	410	240	360	520	230
Wheat, high lysine	10.2	190	780				
Egg, whole fresh[3]	12.8	145	1200	590	440	930	300
Milk, nonfat dry[3]	35.6	53	1450	470	170	880	270

[1]FAO allowance of 14 g corrected for 75 percent digestibility.

[2]BPI-76-1 rice grown in the Philippines in 1969.

[3]Suggested as reference proteins by FAO (1965).

3. The curve depicting minimum requirements for reference protein prepared by the Protein Committee of FAO (Holt, 1960) drops from 2.0 g/kg/day at birth to 1.5 g at 1 year old to 1.0 g at 3 yr, then gradually to 0.6 g at 18 yr and finally below 0.5 g. Special consideration therefore must be given to infants and pre-school children.

4. The Pan American Health Organization and INCAP have suggested that the efficacy of proteins for infants and children should be tested at 2.0 and 1.0 g/kg/day. At a 2.0 g intake, assuming 100 kcal/kg/day, protein calories would represent 8 percent of the total which is the minimum percentage generally accepted for artificial

infant feeding. Protein in human milk yields slightly more than 7 percent of calories. At the lower intake, 4 percent of calories, all proteins are inadequate for growth of human infants. (Graham et al. A.J. Clin. Nutr. 22, 577, 1969).

5. Bressani (Milner, Protein-enriched Foods, p. 51) reported that rural children consumed, in addition to fruits and vegetables, the following amounts (g/day):

Food item	Locality		
	1	2	3
Corn, lime-treated	119	178	174
Beans, black	10	20	10
Milk products	47	5	13
Eggs	5	4	3
Meat	9	14	6
Protein %	12	12	12
Fat %	8	5	7
CHO %	67	73	69

Bressani also reported daily intakes by children of 281 g of corn and 24 g of beans in Guatemala. (Adults from 375 to 400 g of corn in 3 countries)

6. Adequacy of Opaque-2 corn for children

Bressani (Corn Conference, p. 36) fed children 2 to 6 yr of age either 1.8 or 1.5 g of protein and 100 kcal/kg/day from lyophilized corn masa as the only source of protein. Nitrogen balance was slightly higher for the *Opaque-2* corn masa protein than for milk and children gained the same amount when the higher level of protein was fed, but at the lower level corn was less satisfactory than milk. Processing of corn into corn masa or tortilla does not alter its protein quality.

NUTRITIONAL IMPROVEMENT OF WHEAT BY BREEDING

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presented by V. A. Johnson
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Nutritional enhancement of wheat can be achieved by increasing its protein content or by affecting a favorable shift in the ratio of essential amino acids in the protein. To have maximum value, increased level of protein should occur without depression of grain yield or undesirable shifts in essential amino acids. Similarly, improved ratio of essential amino acids should not be accompanied by depression of grain yield or grain protein content if it is to have useful application.

The Agricultural Research Service and University of Nebraska, with financial assistance from the Agency for International Development, are engaged in research on nutritional improvement of wheat by breeding. My discussion will be concerned with our findings to date and the status of our breeding effort.

Grain protein content is a heritable trait. Using Atlas 66 as the genetic source of high protein, we have been able to increase grain protein level by as much as 20 to 25 percent. In practical terms, this means that varieties with 15 percent protein are possible in production situations in which ordinary wheat varieties have only 12 percent.

It has been possible to make simultaneous advances in both grain yield and grain protein content. Our experimental evidence for this comes from extensive trials in the state of Nebraska as well as from an international winter wheat performance nursery (IWWPN).

An advanced experimental line from Atlas 66-Comanche x Lancer produced an average yield of 59.4 bushels per acre at three test sites in Nebraska in 1970 compared to 51.8 bushels per acre for the popular Scout variety. Its grain protein content was 14.4 percent compared to only 11.8 percent for Scout. This is a 23 percent advance in protein content.

The average protein content of Atlas 66 x Comanche, NB67730, at 16 international test sites in 1969 was 16.4 percent with an average grain yield of 52 bushels per acre. Triumph, which made a comparable grain yield, produced grain with only 14.7 percent protein content.

It is not possible to fix grain protein content at a high specified level by breeding. Production environment, particularly soil fertility, has a strong influence on protein content as well as on yield. However, our data do show that high protein varieties can be expected to be superior in protein level to other varieties in an array of environments. Varieties

possessing genes for high protein from Atlas 66 were consistently higher in protein than other varieties tested in the IWWPN in 1969. In Nebraska tests, a high protein variety maintained its protein advantage over the Lancer variety throughout a broad range of soil fertility levels.

Does the high protein trait in wheat have an undesirable effect on the existing ratio of essential amino acids? Our investigation of this question has provided encouraging information. Amino acid profiles were obtained on our Atlas 66-derived lines. Several were comparable in lysine, methionine, and threonine to their low protein parent. More important, there was an increase in the amount of each of these three amino acids per unit weight of grain. The significance of this information is that enhancement of nutritional quality in wheat is possible by breeding for higher protein content.

I believe that further advances in protein content are possible and that, to a limited extent, they can be combined with improved amino acid balance. New high protein wheats have been identified which we have already crossed with Atlas 66-derived lines. New levels of grain protein content could result from such crosses. One of the high protein wheats, Nap Hal (P.I. 176217), is of particular interest because it also appears to produce protein with higher-than-normal lysine content.

Our laboratory has systematically searched the common wheats in the world collection for protein and lysine differences. We are currently evaluating the durum segment of the collection. Protein content of the common wheats ranged from 7.0 to 22.0 percent. The range in lysine content was from 2.2 to 4.2 percent. The genetic component of the lysine variation appears to be approximately 0.5 percent. It is this portion that can be useful for breeding purposes.

Protein content and lysine level are negatively correlated. Among the wheats in the world collection, mean lysine/protein dropped from 3.2 to 2.7 percent as protein increased from 10 to 20 percent. Forty percent of the variation in lysine could be attributed to variation in protein. In contrast, there was a strong positive association of protein content and lysine/dry grain weight. Mean lysine/dry grain weight increased from 0.33 to 0.55 percent as protein content increased from 10 to 20 percent.

Although environmentally induced protein variation is negatively correlated with lysine content of the protein, it does not necessarily follow that genetically high protein wheat will be lower in lysine than ordinary wheat produced in the same environment. Our evidence from amino acid analyses of high protein Atlas 66-derived lines indicates that inherently high protein wheats can be equal to or higher in lysine/protein than ordinary wheats grown in the same environment.

Twelve high protein experimental varieties are now under initial seed increase in Nebraska and Arizona. In these wheats, high grain protein has been combined with high yield, disease resistance, and other desirable agronomic traits.

We have reason to believe that this group of wheats may be well adapted to the large dryland winter wheat production area of central Turkey. For example, a Nebraska-developed winter wheat was released this year by Turkey for commercial production under the name Bolal.

We plan to move seed of the 12 high protein varieties to Turkey next year in sufficient quantity for extensive testing and increase. At the present time our laboratory is doing amino acid profiles on the wheats to determine which exhibit the most favorable ratio of essential amino acids.

Twenty-six high protein experimental lines from our program were released in 1970 as elite germplasm for the use of wheat breeders throughout the world. I have already had requests for this and other nutritionally useful wheat germplasm from 44 researchers and breeders in 16 states and 16 foreign countries. J. C. Craddock who is in charge of the world wheat collection undoubtedly has received many additional requests. The long-range impact of a collective effort of this magnitude on improvement of nutritional quality of wheat should be significant.

Many different high protein and potentially high lysine wheats have been combined in crosses at Lincoln, Nebraska. Several thousand plant selections from the second and third generations of these crosses are undergoing protein analyses in our laboratory and are being propagated in Nebraska and Arizona in 1971. We will make lysine determinations on the material as our laboratory facilities and time permit. It is our intention to make the lines with the best nutritional possibilities available to developing countries for agronomic evaluation. Seed of agronomically most-promising lines could be returned to our laboratory for complete amino acid determinations.

Identification of agronomically superior winter wheat varieties for developing countries has been aided by the establishment of the IWWPN in 1969. Such varieties as Bezostaia, Blueboy, and Sturdy have emerged as outstanding genotypes for use in the continued breeding improvement of wheat. We are using them heavily in our breeding effort.

Development of the twelve high protein winter wheat varieties which are being increased for possible use as commercial varieties in Nebraska and in Turkey are estimated to have cost $250,000. This compares with an estimated cost of $100,000 per variety for the last 10 winter wheat varieties developed and released by the Nebraska Agricultural Experiment Station.

These wheats and others that will follow do not solve the wheat protein problem. We believe, however, that they can make a significant contribution toward its alleviation.

NUTRITIONAL IMPROVEMENT OF WHEAT BY FORTIFICATION

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I will approach the topic "wheat fortification" from the point of view of a food technologist with a knowledge of nutrition rather than that of a nutritionist with a knowledge of food technology. I will initially discuss the fortification of wheat flour with particular emphasis on the cost and then devote some time to a discussion of fortifying wheat kernels. There is a tendency to use the term "wheat" to cover both wheat flour and wheat kernels in discussions of fortification and on occasion this has led to some confusion. The technology of fortifying wheat flour is rather straight forward; there are however problems of fortifying whole wheat kernels which I will mention later on.

Fortifying Wheat Flour: Nutrients and Costs

Tables I and II present the costs and levels of thiamine, riboflavin, niacin, iron, and vitamin A which are added to wheat flour sent to developing countries under the Title II provisions of P.L.480. (Vitamin A is not added to wheat flour sold in the United States.) I have included in these tables data on L-lysine. The specific levels of iron and lysine, which I have presented, may be changed as our knowledge of their efficacy and human need increases. Nevertheless, the conclusions we can make from the data as given will be still valid.

In the United States, we have been adding thiamine, riboflavin, niacin, and iron to our wheat flour since the early 1940s. The method of addition, the monitoring procedures, and the equipment are all worked out. The costs of any quality control program associated

TABLE I – NUTRIENTS FOR FORTIFYING WHEAT FLOUR

Nutrient	*Cost per kg (dollars)*
Thiamine	14.75
Riboflavin	32.00
Niacin	3.25
Vitamin A	5¢ per million IU
Iron (Ferric Phosphate)	1.10
L-lysine	2.20[1]

[1]Current costs in the United States for very small quantities are approximately $3.70 per kg. However, $2.20 per kg. is a realistic cost estimate when production is in the range of 500-1000 tons per year; when production reaches 50,000 tons per year, cost will be around $1.50 per kg.

TABLE II – WHEAT FORTIFICATION: NUTRIENT LEVELS AND COSTS

Nutrient	*Amount per kg. of Flour*	*Cost per metric ton of flour $*
Thiamine	4.18 mg	.062
Riboflavin	2.52 mg	.081
Niacin	30.14 mg	.068
Iron	26.40 mg	.029
Vitamin A	10,000 IU	.50
Subtotal		.76[1]
L-Lysine	2 gms	4.40
TOTAL		5.14[1]

[1]Cost of premix preparation would add approximately 25 cents to fortification cost per metric ton.

with fortification are minimal. The price of the feeders to add the nutrients to the flour is generally about a thousand dollars. Mr. Clinton Brooke has developed a feeder capable of handling light or heavy feed rates with an accuracy of plus or minus 2 or 3 percent. The probable cost of such a feeder which would be very useful in developing countries is probably about $50.00.

Since the late 1960s, the U. S. Government has been adding dry vitamin A to wheat flour sent overseas under P.L.480. Vitamin A is added in the form of gelatin encapsulated microdroplets of vitamin A. The gelatin coating protects the vitamin and imparts a high degree of stability. These particles, sometimes referred to as "beadlets," can be supplied in a suitable particle size range for admixture with flour without risk of segregation during handling and storage.

Table II shows that the cost of adding lysine to a vitamin-mineral premix is about 6 times the cost of the other nutrients. When we add the 25 cents cost of premix preparation to the ingredient cost, the ratio drops slightly to approximately 5½. If the final cost to fortify one metric ton of flour is $5.40, then the cost of lysine is 80 percent of the total.

If we assume a metric ton of flour costs approximately $150 and the cost to fortify this metric ton with all the ingredients but lysine is $1, then the relative cost is approximately 0.7 percent. I think we can all agree that at this low cost it would make little sense to spend research and development money and effort to breeding-in these vitamins and iron into wheat. Obviously, breeding lysine into wheat flour is a different story. Here the cost of fortifying wheat flour is approximately 3½ percent of the cost of the wheat. I would venture an opinion that if breeding lysine into wheat were to add an additional 5 percent of the cost, this would still be tolerable for the following reasons. With fortification we have to get the wheat to the mill where we can add the appropriate nutrients. However, with breeding we don't have to worry about central location. Of course, there is the paradox that if we do breed lysine at a reasonable cost into the wheat we still have the necessity of getting this material to the mills where we can add the other vital nutrients such as vitamin A, thiamine, and iron.

Lysine Production Facilities

The question is frequently asked what is the minimum size plant for producing lysine. As you all know lysine is produced by a chemical process and by a fermentation process. The best information I have on the subject is that a minimum size plant for economical production of lysine via a chemical process is in the vicinity of 10 million pounds annually. The minimum size fermentation facility is in the vicinity of 2(?) million pounds annually. It can be estimated that this miminum size facility would cost 3½ - 4 million U.S. dollars for capital equipment if it were not part of a larger fermentation operation. It could cost another 1½ million dollars for construction of foundation, power, utilities, etc. The operating costs are difficult to estimate without knowing the details of the carbohydrate source and local conditions. A rough estimate would be ½ million dollars per year. The water requirements for a fermentation plant would be 2 million gallons daily. In view of the large capital impact and operating costs, it makes sense to construct a lysine producing unit onto an existing fermentation facility. For example, a plant which is producing MSG or antibiotics would be a natural choice.

Effect of Lysine on the Nutritive Value of Wheat Flour

In Table III we can see how the addition of lysine to wheat flour increases the utilizable protein. In our office, we have chosen to speak of lysine addition as increasing the utilizable protein rather than talking in terms of increasing protein quality. We have found that the term protein quality, while appropriate in a technical sense, is frequently misleading to people without a background in nutrition. Quality is really an esoteric term which is difficult to apply numbers to in any cost-benefit or cost-effectiveness analysis. However, the economic and political scientist in government can readily understand the concept of biologically utilizable protein and can economically quantify its increase via amino acid addition.

TABLE III
EFFECT OF LYSINE ON THE NUTRITIVE VALUE OF WHEAT PROTEIN

Food	*Reference*	*Protein (by chemical analysis)*	*Utilizable Protein*	*Increase in Utilizable Protein per 100 gms Food*
		%	%	gms
White wheat flour	1	13.75	3.20	
White wheat flour +0.2% lysine-HCl		13.94	5.34	2.14
Water bread	2	15	7.3	
Water bread +0.3% lysine-HCl		15	10.0	2.7

[1]Hegsted, D.M. in "Protein-Enriched Cereal Food for World Needs," pp. 38-48, published by American Association of Cereal Chemists, 1969.

[2]Jansen, G.R. (1969) American J. Clin. Nutr. 22, 38-43.

The data of Hegsted and Jansen, while differing in the level of utilizable protein, agree on the increase which can be achieved via the addition of lysine. They both show that the utilizable protein in 100 grams of wheat can be increased approximately 1 gram by the addition of 0.1 gram of lysine. If we assume that human grade lysine can be purchased for $1 per pound, the cost of the additional one gram of utilizable wheat protein is 0.022 cents. This is equivalent to ten cents per pound of protein. From a straight mathematical standpoint it is hard to see how any other source of protein is cheaper. This is not to suggest that wheat fortification with lysine to increase available protein in the diet is the answer in every country under all circumstances. Obviously if a country has no wheat and has to import the wheat, but it does have other sources of protein available, than wheat fortification might not make economic sense.

Wheat Kernel Fortification

In the background papers sent prior to the meeting, there is an excellent discussion by Drs. Fred Senti and Jim Pence regarding the fortification of whole kernel products. Workers at the Western Utilization Research and Development Division in Albany, California have devised procedures for fortifying whole and cracked wheat with materials such as soy protein to give final table products with protein contents up to 20 percent of solids. Of particular relevance to our workshop is their work on fortification of wheat with 0.1 to 0.2 percent of L-lysine monohydrochloride. They found that the most practical way to fortify wheat kernels with lysine is to infuse the amino acid into wheat kernels to the extent of 10 percent and then blend this into untreated wheat at a ratio of 1:99 for each 0.1 percent addition of the lysine desired. To assist the infusion, they scarified the bran lightly by passing the wheat through a pearling mill. The scarified wheat, after a 3 hour soak in 35 percent L-lysine monohydrochloride at 106°F followed by draining and a one hour tempering period before drying, will take up 10-12 percent of the lysine salt. It was reported that wheat thus treated resembled untreated wheat quite well. The treated kernels are almost impossible to detect when mixed with untreated wheat. The USDA workers concluded that it is technologically possible to fortify wheat kernels with lysine on a large scale.

Bulgur in dry form is delivered as parboiled, blanched, and crushed wheat. The U.S. Government this past year has shipped over 5 million pounds of bulgur fortified with 0.1 percent lysine. In the industrial process used in fortifying the bulgur, all the kernels have been treated with a lysine solution rather than only 10 percent. It is not clear as to the degree of lysine lost during subsequent rinsing and cooking of bulgur fortified in this manner. WURDD have used a modified rinse test, developed for enriched rice, to estimate loss of lysine during rinsing. It appears that roughly 25 percent of the lysine leaches out of the treated kernels if they are subjected to rinsing. In practice, this would be determined by the severity of the rinsing step. The Department of Agriculture has recommended unofficially to industry that they add an additional 25 percent lysine. In other words, to have the final product contain 0.1 percent lysine, the Department would like to have the fortified bulgur contain immediately after processing 0.125 percent.

One of the problems I have found in discussing fortification of whole wheat is the lack of faith in the accuracy the methods of lysine analysis. USDA workers at Albany have developed a procedure to determine lysine in wheat or bulgur by iron exchange chromatography. This new method has not yet been published. The matter of analytical chemistry

is beyond the scope of this talk. Suffice to say there is some disagreement amongst the workers on the accuracy and therefore meaning of current methods of lysine analysis. This problem will have to be cleared up if lysine fortification of kernels is to become a meaningful activity.

Concluding Remarks

In today's remarks, I have tried to show that fortification of wheat flour is a nutrition improvement approach which is available today for use in developing countries. This is especially true for vitamins and minerals. Let me wonder out loud with Lyle Schertz why more is not being done with vitamins and minerals. They are inexpensive, and methods of addition and monitoring at the flour mills require only a minimal technical competence. Common sense tells us that with little effort and cost, vitamin and mineral fortification can prevent or reduce deficiency diseases such as vitamin A-blindness, beri-beri, pellagra, and iron anemia.

I have indicated that lysine fortification of wheat flour is the least cost way to get additional usable protein into the stomaches of wheat-eating people. Availability of lysine in developing countries, not cost, is the major roadblock. Poor countries do not want to use scarce foreign exchange to purchase lysine from external sources. The breakthroughs in lysine production in developing countries will have to come in large countries such as Brazil. It may also happen in a small country as part of regional marketing and trade agreements which would involve the exchange of goods for lysine, not money.

Fortification of wheat kernels may not be a feasible or significant approach in actual practice. If wheat is to be milled in large facilities, it makes no sense to fortify the kernels prior to milling. And it is almost impossible to break into the distribution system to fortify wheat kernels prior to milling in "primitive" village-level operations.

It is possible that the benefits of wheat flour fortification may have gotten lost in the emotional issue of lysine. The emotionalism surrounding lysine seems to be practically identical to that surrounding fluorine addition to water. If this is the case, the real losers are the poor people suffering from vitamin, mineral, and protein deficiencies.

BREEDING OF RICE FOR HIGH PROTEIN CONTENT AND RELATED PROBLEMS

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Rice samples from farmers' fields in the Philippines have varied from 6.3 to 9.2 percent protein (brown rice). This variability occurred within the IR 8 variety. Experimental plots of IR 8 in which improved management practices were followed have produced as high as 11.6 percent protein. High rates of nitrogen fertilizer (150 kg/ha) were used and the yield of rough rice was over six metric tons per hectare.

Effect of New Technology on Protein and Yield

The new high yielding improved plant type varieties, such as IR 8, may not be genetically higher in protein content than the traditional tropical varieties. However, since the new strains can utilize higher rates of nitrogen fertilizer we can expect higher amounts of protein as well as higher grain yields. As farmers become more experienced in carrying out the new management practices, this increase should be more apparent. It has been estimated that about 6 percent of the 1969 Asian rice crop was planted to the improved plant type varieties.

Environmental factors affecting protein content include season (wet or dry), soil fertility, and time and rate of nitrogen fertilizer applied.

Generally, protein content is higher and grain yields are lower in the wet season (monsoon season). The higher yields produced during the dry season are due to higher light intensity which makes it possible to utilize higher rates of nitrogen fertilizer.

In 1970, the wet season was an exception as protein content was lower than in the dry season. Probably this was due to lower than normal light intensity during the period from panicle initiation to maturity of the rice crop. Rough rice yields were lower than normal as well.

Quality of Protein

Based on cooperative studies with Dr. R. Bressani, lower PER values were obtained on high protein compared with low protein rice (5.7 to 14.3 percent). The decrease in protein quality was proportionally less than the increase in protein content.

The nutritional value of milled rice increases with its protein content. (Protein content x relative nutritional value). This is an important consideration when the high daily consumption of rice is considered.

High protein rice shows slightly lower percentage of lysine, tryptophan, and threonine.

There does not appear to be any adverse effect on high protein content (up to 14 percent) on cooking behavior.

Selecting and Breeding for High Protein Content

BPI-76, a tall variety which is somewhat higher yielding than most traditional varieties, appears to be genetically higher in protein. Samples of over 14 percent protein have been obtained from BPI-76 using late applications of nitrogen fertilizer.

The world collection of rice varieties of IRRI was screened for protein content. Six varieties were selected for use in crossing to IR 8. These crosses have been carried through seven generations. Protein content of plant selections have varied from 5.8 to over 15 percent. In at least some cases, some of this variability is thought to be genetic.

Replicated yield trials conducted in 1970 from lines selected from the above mentioned crosses have varied from 8.2 to 14.4 percent.

High yielding strains showing high protein content have not been found. However, lines showing consistently high protein content have been identified. They will be tested under a range of management practices to determine maximum yield potential. Yields as high as 5 metric tons rough rice have been produced by these lines.

BPI-76 is being used as a parent for high protein, but the lines selected from these crosses have not been fully evaluated.

Lines suspected of having higher protein content have been selected from the regular breeding program. One line, IR 480-5-9-3-3 from the cross nahng Mon S4 x taichung native 1, is being tested.

The next step in the breeding program will be to intercross apparent high protein lines of divergent origin with the hope of combining different genes for high protein content.

Screening for other sources of high protein will continue.

New high yielding varieties being developed in Korea indicate that they may be genetically higher in protein content than the japonica varieties now grown. The new strains were developed from japonica x indica crosses and in one 1970 experiment they averaged 10 percent protein compared with 8.7 percent for japonica varieties. Brown rice yields were 5.3 metric tons per hectare for the new strains and 4.7 tons for the japonica varieties.

Table I: Mean protein and mean grain yield from farmers' field, by variety. Laguna, 1970 WS. (Statistics Department, IRRI).

Variety	No. of farms[1]	Range of fertilizer used (kg/ha N)	Mean grain yield (kg/ha)	Mean protein content (%)
IR 8	19	18 - 61	4276	7.50
IR 5	5	36 - 54	3991	7.40
IR 20	4	36 - 51	3398	8.12
IR 22	2	50 - 54	3299	7.45
C4-63	3	36 - 61	4310	8.47
Malagkit	3	20 - 42	2965	8.50
Total	36			

[1]Four samples were taken from each farm.

Table II: Mean protein and mean grain yield from farmers' fields for different varieties. Laguna, 1970 dry season. (Statistics Department, IRRI).

Variety	No. of farms[1]	Range of fertilizer used (kg/ha N)	Mean grain yield (kg/ha)	Mean protein (%)
IR 8	3	0	3612	7.3
	4	33 - 43	4669	8.0
	16	51 - 84	4527	8.2
IR 20	4	54 - 81	4517	8.9
Intan	3	63 - 99	6985	6.8
IR5	2	46 - 57	4853	7.7
C-4	2	40 - 97	3303	8.3

[1]Data are averages of 4 sampling cuts per farm.

Table III: Comparisons between mean yield and mean protein from season to season, from rice farms in Laguna, 1970. (Statistics Department, IRRI).

Farmer	Dry Season			Wet Season		
	Fertilizer level	Mean protein %	Mean yield (kg/ha)	Fertilizer level	Mean protein %	Mean yield (kg/ha)
IR8						
1. Casubha	43.04	9.2	6932	27.39	8.0	5108
2. Nervaez	67.50	9.1	4787	40.50	7.9	5025
3. Consignado	63.00	8.7	5335	60.75	7.9	5149
4. Notario	36.00	8.0	4467	36.00	6.3	4945
5. Britiller	54.00	8.7	4240	18.00	8.4	4850
6. Calabit	52.50	7.4	2562	50.62	7.6	3499
7. Cabantot	33.75	6.8	4119	54.00	7.7	4790
8. de Guzman	0	7.2	2182	36.00	7.7	3895
9. Rana	73.63	6.8	3618	55.23	7.6	3806
C4						
1. Brozas	97.20	9.1	3767	36.00	8.6	4547
IR20						
1. Taklan	70.87	8.6	3762	36.00	8.1	2685

Table IV: Protein content and grain yield of four lines, for dry and wet season, at different plant spacing, IRRI, 1969.

Plant density	IR8		IR305-4-12-1-3		IR127-80-1-10		Peta	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Broadcast	6.1	6.9	6.1	7.3	6.0	7.5	7.8	8.7
	(3572)	(5824)	(4250)	(4932)	(4934)	(4659)	(3207)	(2801)
20 x 20	6.4	7.6	6.2	7.4	6.4	7.8	6.2	9.0
	(2864)	(6094)	(4159)	(5618)	(4328)	(4746)	(4336)	(2845)
30 x 30	6.7	7.6	7.3	7.4	7.5	8.4	6.7	8.6
	(2840)	(6069)	(4823)	(5540)	(3554)	(4928)	(4571)	(3289)
40 x 40	6.6	7.9	5.9	7.7	8.6	8.5	5.9	7.4
	(2764)	(5697)	(4028)	(5460)	(2950)	(4067)	(4100)	(3071)
50 x 50	7.0	8.7	7.0	8.1	9.3	9.0	7.1	8.5
	(2456)	(5800)	(3918)	(5233)	(2728)	(3687)	(3534)	(3356)
100 x 100	9.0	9.5	7.5	9.9	10.9	11.3	7.4	8.6
	(1300)	(2725)	(1463)	(2455)	(827)	(1286)	(1804)	(2706)

Data are averages of 3 replicates. No nitrogen was applied.

Source of data: Experiment of plant population and nitrogen response in flooded rice, Department of Agronomy, IRRI.

Table V: Relationship between applied nitrogen and the per hectare yields of rough rice and protein in brown rice (average of 6 plant densities. (Agronomy Department, IRRI).

	Protein yield (kg/ha)			Rough rice yield (kg/ha)		
	Nitrogen applied (kg/ha)			Nitrogen applied (kg/ha)		
Varieties	0	40	80	0	40	80
'69 Wet season						
IR8	330	378	361	5374	5673	5614
IR305-4-12-1-3	319	370	394	4873	5364	5742
IR127-80-1-10	261	270	310	3895	4135	4460
Peta	189	199	188	3011	2448	2990
	Nitrogen applied (kg/ha)			Nitrogen applied (kg/ha)		
'70 Dry season	0	75	150	0	75	150
IR8	246	385	473	4050	5843	6752
IR305-4-12-1-3	286	399	496	4620	6139	6888
IR127-80-1-10	163	253	317	2618	3892	4255
IR20	219	324	437	3518	5031	5986
IR22	195	330	400	3090	4689	5473
Peta	167	233	213	2958	3530	2952

Table VI: Yield of rough rice and milled rice protein and percentage of total milled head rice and protein content (Bicol).

Varieties	N-rates kg/ha[1]	Rough rice kg/ha[2]	Total Milled rice %	Head rice %	Protein content[3]		Protein yield of milled rice kg/ha
					Brown rice	Milled rice	
IR8	0	5117	69	61	7.0	6.7	237
	60	5684	69	62	7.0	6.5	256
	120	6296	70	63	8.5	7.8	343
	150	6652	70	64	10:1	9.4	435
IR5	0	4532	67	55	7.1	6.6	201
	60	5953	67	56	7.9	7.0	281
	120	5575	68	61	9.7	7.9	300
	150	4744	69	62	10.6	10.1	328
IR20	0	4547	68	62	7.3	7.0	218
	60	5258	69	64	8.0	7.2	260
	120	6051	68	64	9.0	8.5	351
	150	5268	67	64	9.9	9.1	323
Peta	0	3815	68	55	7.1	6.5	168
	60	4146	63	46	8.4	8.0	210
	120	3150	68	58	9.0	8.7	187
	150	3062	68	60	10.4	9.2	191
BPI-76	0	4005	68	63	8.8	8.2	223
	60	4111	68	62	9.3	8.7	243
	120	4622	69	66	9.6	9.0	287
	150	4506	69	65	11.7	11.2	347
C4-63	0	3840	69	62	7.2	7.1	187
	60	4862	68	64	7.9	7.4	246
	120	5356	69	64	8.8	8.2	304
	150	5162	70	64	9.2	8.8	317

[1]Treatments 30 N and 90 N are omitted here as otherwise the table would be too long.

[2]Data cited are from the IRRI Agronomy Department.

[3]Protein content at 12% moisture.

Table VII: Yield of rough rice and milled rice protein and percentage of total milled head rice and protein content (Maligaya).

Varieties	N-rates kg/ha[1]	Rough rice kg/ha[2]	Total Milled rice %	Head rice %	Protein content[3]		Protein yield of milled rice kg/ha
					Brown rice	Milled rice	
IR8	0	3737	69	49	7.3	6.3	163
	60	4642	69	55	7.8	6.8	218
	120	5948	71	58	8.0	7.3	306
	150	5264	71	58	9.9	8.5	318
IR5	0	3987	67	50	6.6	6.1	164
	60	5461	70	56	8.1	7.3	279
	120	5383	71	58	8.6	8.1	310
	150	5099	71	59	9.9	8.9	320
IR20	0	4010	71	58	6.9	6.1	173
	60	5797	71	61	8.3	7.6	312
	120	6144	71	64	8.7	7.6	332
	150	5914	71	65	9.4	8.5	356
Peta	0	4110	67	51	7.1	6.2	172
	60	4280	71	57	8.1	7.4	223
	120	4539	72	60	8.9	7.8	254
	150	4745	72	62	8.0	7.6	257
BPI-76 (M.5)	0	2697	69	58	7.9	7.1	133
	60	4133	70	57	9.6	8.8	253
	120	4258	70	57	10.9	9.9	293
	150	3648	69	59	11.2	9.4	237
C4-63	0	3682	70	59	7.6	6.4	164
	60	4813	70	59	8.2	7.4	250
	120	5365	70	61	8.6	8.0	302
	150	5071	71	61	8.8	7.9	283

[1]Treatments 30 N and 90 N are omitted here as otherwise the table would be too long.

[2]Data cited are from the IRRI Agronomy Department.

[3]Protein content at 12 percent moisture.

Table VIII: Protein content of brown rice of 4 varieties as affected by the organic matter and nitrogen applied.*

Variety	80 kg N/ha		120 kg N/ha		160 kg N/ha		Var.
	No. Org.	Org.	No. Org.	Org.	No. Org.	Org.	Mean
Jinheung	6.5	6.4	6.8	7.0	7.8	7.1	6.93
Kimmaze	6.3	6.5	7.3	6.4	7.5	7.1	6.85
IR-8	8.3	10.4	9.9	11.0	10.1	11.1	10.13
T(N)1	9.0	8.5	10.3	10.6	10.2	11.1	9.95
N level mean	7.53	7.59	8.58	8.75	8.9	9.1	8.46

*Data taken from the Journal of the Korean Society of Crop Science, Vol. 7: 79-84, 1969.

Table IX: Rough rice yields and protein content IR667-98 lines grown at two nitrogen levels, Office or Rural Development, Suwon, Korea (unpublished data)

			Brown rice yields and protein content	
			150 kg N/ha	200 kg N/ha
IR667-98-1-2	(Suwon 213)	Brown Rice T/ha	5.6	5.3
		Protein (%)	9.0	9.6
IR667-98-1-3-10	(Suwon 214)	Brown rice	5.5	5.4
		Protein	8.9	10.6
IR667-98-2-1-7	(Suwon 215)	Brown rice	5.2	5.2
		Protein	9.8	10.8
IR667-98-2-1-20	(Suwon 217)	Brown rice	5.2	5.2
		Protein	9.7	10.6
IR667-98-2-2-24	(Suwon 218)	Brown rice	5.4	5.4
		Protein	9.6	11.0
	Jinheung	Brown rice	4.6	5.0
		Protein	8.7	8.6

Table X. Effects of level of nitrogen on grain yield and protein content of brown rice at three BPI stations. 1969 wet season.

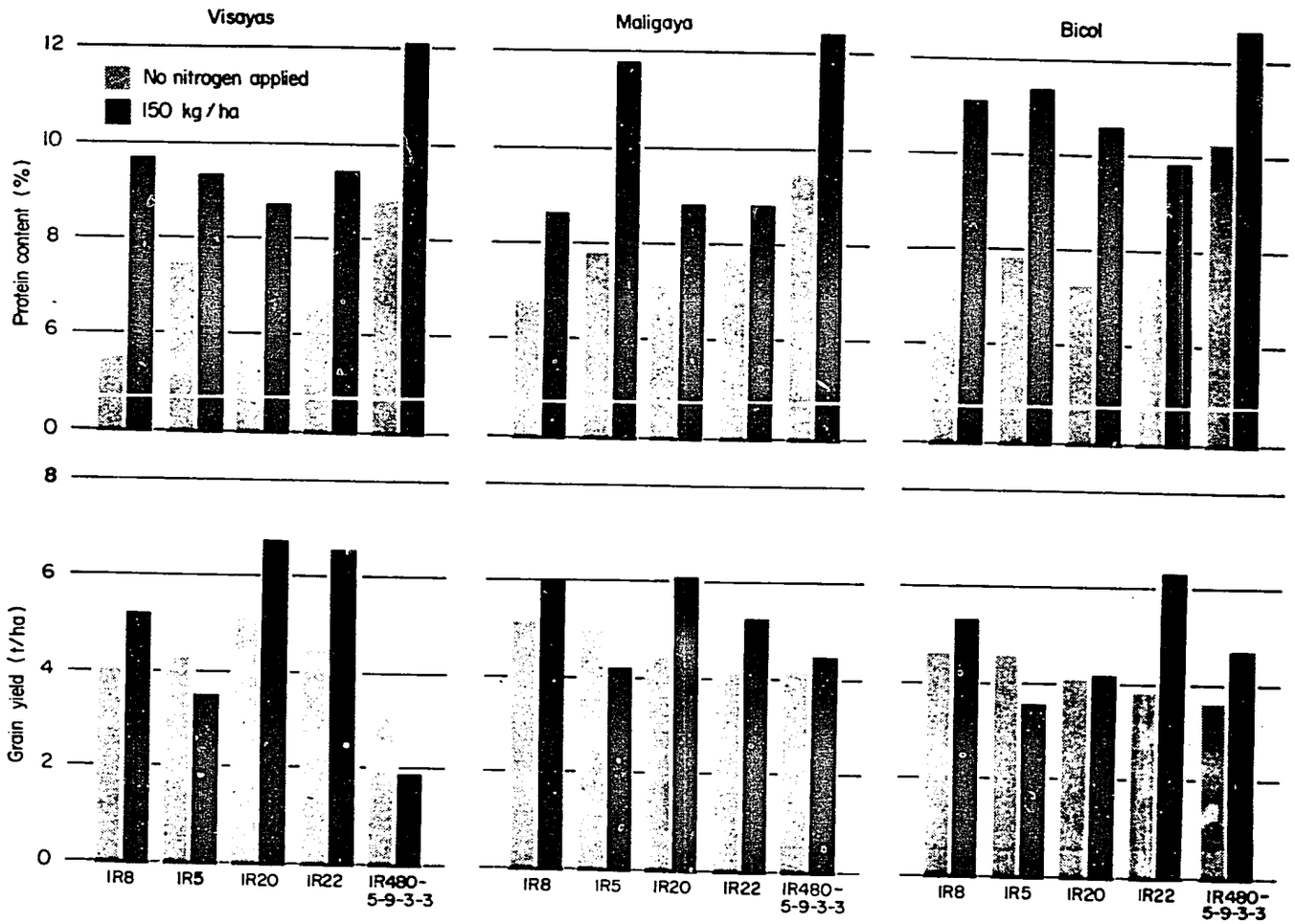

Table XI. Effects of level of nitrogen on grain yield and protein content of brown rice. IRRI, 1969 wet season.

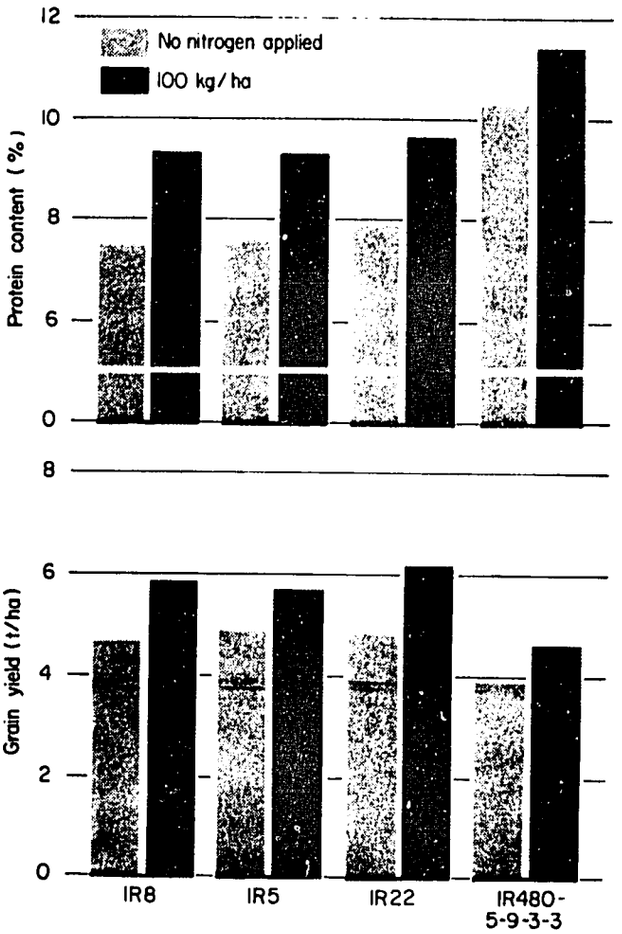

Table XII: Summary of protein quality indexes for four milled rice samples and casein - cooperative studies between IRRI and Dr. R. Bressani, Instituto de Nutricion de Centro America y Panama.

		0 to 5% - Protein Diets				High - Rice Diets		
Protein Source	Protein Content (%)	PER[b] (5% Protein)	Net Protein Ratio	Nitrogen Growth Index	Relative quality[c]	PER[b] (90% rice)	Nitrogen Growth Index	Relative quality[c]
Intan	5.63	2.56	3.71	3.49	80.0	2.04	2.37	47.0
IR8	7.32	2.20	3.36	3.25	75.0	2.02	2.30	45.6
IR8	9.73	1.94	3.07	3.04	70.5	2.02	2.17	43.1
BPI-76-1[a]	14.3	1.53	2.60	2.47	57.4	1.85	2.12	42.1
Casein	- - -	2.20	3.36	3.23	75.0	- - -	3.78	75.0

[a]Corrected for differences in casein values from the two experiments.

[b]Protein efficiency ratio.

[c]Based on a value of 75.0 for casein.

Table XIII: Taste panel scores of lines and varieties differing in protein content, Chemistry Department, IRRI in cooperation with UPCA.

Selection or Variety	Protein (%)[a]	Amylose (%)[a]	Mean Taste Panel Scores[b]			
			Tenderness	Cohesiveness	Color	Gloss
IR1100-185-7-4	9.1	26.2	5.2	4.0	2.2	4.0
IR1100-89-2-6	11.1	23.1	4.5	3.2	2.2	4.0
IR1103-64-4-1	8.8	27.1	4.7	3.7	1.5	4.3
IR1103-15-8-5	11.6	25.2	3.5	2.0	2.2	3.7
IR1103-15-9-8	12.9	25.0	3.2	2.0	1.8	3.3
IR8	9.9	26.0	3.7	2.7	1.5	4.0
BPI-76-1	10.0	26.2	5.2	4.5	2.8	5.3
		LSD (5%)	1.6	1.4	1.3	1.3

[a]% at 12% moisture.

[b]By a panel of six judges. Numerical scores from 1 to 9 were assigned, a score of "1" representing the lowest expression of the property in question and a score of "9" the highest expression.

Table XIV: Aminogram of milled rice sent to INCAP for PER studies.[a]

Protein content (%) at 12% moisture	5.68	7.32	9.73	14.3	LSD (0.05)
	Amino acid content (g/16.8g N)				
	Intan	IR8	IR8	BPI-76	
Alanine	5.99	6.04	5.66	6.24	
Arginine	7.90	8.78	8.82	8.58	
Aspartic acid	9.59	9.97	9.46	10.4	
Cystine	1.81	1.81	1.45	1.42	0.27
Glutamic acid	18.3	19.1	18.7	21.1	1.06
Glycine	4.82	4.80	4.52	4.66	0.20
Histidine	2.45	2.45	2.48	2.48	
Isoleucine	4.89	5.10	4.78	5.34	
Leucine	7.84	8.32	8.20	9.64	0.92
Lysine	4.27	3.77	3.69	3.35	0.32
Methionine	3.45	3.02	2.44	1.80	0.36
Phenylalanine	5.55	5.74	5.66	6.25	0.41
Proline	4.73	5.04	4.79	4.66	
Serine	6.31	5.68	6.27	6.92	
Threonine	4.10	4.10	3.78	3.75	0.20
Tryptophan[b]	1.35	1.26	1.05	0.97	0.08
Tyrosine	5.02	5.34	5.34	5.85	
Valine	6.24	6.55	6.51	7.30	
Ammonia	3.70	2.98	2.86	2.28	0.46
TOTAL	108.31	110.29	106.46	112.98	
Nitrogen recovery	102.7	101.3	98.5	99.8	

[a]Values for cystine, isoleucine, methionine, serine, threonine and valine were corrected using the factors of Kohler and Palter (Cereal Chem. 44: 512 (1967).

[b]Colorimetric assay of Pronase digest by the Opienska-Blauth reagent (Anal. Biochem. 6: 69 (1963).

Table XV: Protein level of brown rice from four plantings of selected varieties.

Acc. No.	Variety Name	1966 Wet Season		1966-67 Dry Season	1967 Wet Season	
		Planting material	Crop	Wet Basis (%)	No N	120 kg/ha N
2169	Chok-jye-bi-chal+	15.1	15.0	15.4	15.5(310)	16.0(340)
2171	Chow-sung	15.3		14.6	15.4(83)	16.2(180)
3192	Crythroceros Korn	16.2	11.5	13.5	14.3(40)	15.4(55)
3165	Omirt 39+	14.7	13.6	12.8	14.3(240)	14.8(425)
2714	Rikuto Norin 20+	14.5	13.5	14.3	14.0(1255)	14.8(1115)
2251	Santo+	16.7	14.2	13.8	13.7(525)	13.6(815)

+Classified as high protein based on 13.5% protein content in both planting material and resulting crop, 1966 wet season.

Table XVI: Rough rice yield and protein content of selected lines from replicated yield trials IRRI, 1970 dry and wet seasons.

IR No.		Dry			Wet		
		A	B	AVE.	A	B	AVE.
IR1100-78-3-3-3	Yield	4595	4999	4597	2544	2744	2644
	Protein	11.6	12.2	11.9	10.0	10.3	10.2
IR1100-82-3-3-1	Yield	8938	8525	8732	3572	3518	3545
	Protein	11.4	10.7	11.1	8.5	8.6	8.6
IR1100-89-2-6-3	Yield	4277	3555	3916	2517	2949	2633
	Protein	12.8	13.2	13.0	10.1	10.2	10.2
IR1101-18-3-4-2	Yield	5967	5070	5518	2834	2443	2641
	Protein	11.6	11.4	11.5	10.5	10.3	10.4
IR1102-25-3-2-4	Yield	3962	2896	3429	2064	2518	2291
	Protein	12.2	12.0	12.1	9.4	10.3	9.9
IR1102-27-2-3-1	Yield	1859	2278	2068	1835	2126	1980
	Protein	13.0	12.6	12.8	11.6	11.5	11.6
IR1103-1-3-5-1	Yield	5341	4636	4988	1983	2326	2154
	Protein	13.1	11.1	12.1	11.2	11.4	11.3
IR1103-15-8-6-3	Yield	5203	4457	4830	2424	2817	2621
	Protein	12.5	12.6	12.6	12.4	12.5	12.4
IR1103-15-9-4-4	Yield	3411	3548	3480	1637	2055	1346
	Protein	13.9	13.2	13.6	13.5	13.4	13.4
IR1103-15-10-2-3	Yield	4954	4465	4710	2617	2995	2806
	Protein	13.2	12.2	12.7	12.7	11.9	12.3
IR1103-66-4-2-4	Yield	4471	3857	4164	3404	3986	3695
	Protein	11.4	11.2	11.3	11.8	11.5	11.6
IR1103-66-4-3-3	Yield	4052	4180	4116	2763	2899	2831
	Protein	12.6	12.6	12.6	13.0	12.5	12.8
IR1105-12-2-3	Yield	3767	3028	3398	1460	1549	1504
	Protein	12.2	13.4	12.8	12.8	13.9	13.4
IR8	Yield	6410	5817	6114	1445		
	Protein	11.2	11.6	11.4	8.2		
BPI-76-1	Yield	3733	3624	3678	1652	669	1161
	Protein	11.8	12.8	12.3	10.8	11.9	11.4

NUTRITIONAL IMPROVEMENT OF RICE BY FORTIFICATION

Stanley Gershoff
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I think we all agree that the health of the people in developing countries is not what it should be, and I think we all agree neither is their nutrition. I am interested in seeing whether nutrition programs may be of some value in improving the health of the people in developing countries. And I have had an opportunity over the years to work in Thailand which is not exactly typical of developing countries but provides a good laboratory. There are in Thailand a large number of people who are interested in nutrition, and, interestingly, almost everyone of them has his own pet ideas on what kind of nutrition program would work best.

Fortification theoretically offers certain advantages over some of the other programs that I have heard discussed over and over again in Thailand. I think that maybe one of the major advantages of fortification, whether it is done by breeding the nutrients into the rice (incidentally, rice makes up 80–85 percent of the calories of the people in rural Thailand) or whether it's done by the addition of some fortification mixture to the rice, is that fortification does not require special education of the people. They continue to eat in the way they have eaten before. It doesn't result in changes in eating habits. And this supplies a real advantage. When you have a fortification program involving something as basic as rice in a country like Thailand, you are affecting all of the meals that are being eaten as contrasted to a school lunch feeding program with or without special protein supplements where you are giving children one meal a day five days a week.

Now we also have some problems with fortification. The first one we have come up against immediately is the cost. I don't know exactly how much a fortification program will cost in Thailand. Let me suggest that with addition of lysine and threonine that the cost may come to $1.50 to $2.00 per year per person. That may not seem like a lot of money in a country like the United States; however, in a country where, I'm told, 40¢ per person a year is all that is spent on all health services, a program that requires $1.50 appears rather large. There is also a question of whom we are trying to benefit. If a fortification program only benefits a small segment of the population, such as the preschool children, and you are feeding everybody else, then the cost is even greater than $1.50 per capita. This kind of question comes up all the time.

There's another problem I think that is occurring in the developing countries, of Asia at least, which I've become aware of these last few years in Thailand. You begin to hear people saying that the Japanese are accomplishing with their salesmen what they couldn't accomplish with their army. And fortification, as it is viewed by many people, means another way of taking their hard currency and shipping it to Japan. This is something that we cannot ignore. It is, fortunately, something that I don't have to worry about at this point in my work.

Now just what are we doing? We have set up a study, a pilot field study, and next month a full field study, to try to determine what the health benefits of a fortification program might be. I think there are very good reasons for doing this. I don't see how it is possible to sell fortification to prime ministers or ministers of health unless you can give them some kind of estimate of what you can give them for their money. I don't think that this estimate can be done in terms of nitrogen balance. I don't think it can be done in terms of urinary excretion or blood levels of vitamins. I think it has to be done in something that everybody clearly understands. This is what we hope that we will be able to do in Thailand.

There are certain problems in methodology. Fortunately, there are now two types of fortification mixtures we can use. One is an artifical rice pellet or rice fortification grain I may refer to as RFG. This is a synthetic rice pellet. We can tailor it as we wish. It is not perfect. We have problems of texture, conceivably problems of taste. Probably the biggest problem with RFG is loss of nutrients in cooking and this would be enormous if the kind of pellet we use was employed in Pakistan where rice is cooked with large amounts of water. Where we are working, rice is steamed and our analyses indicate that loss is minimal. There is another problem and this has to do with the color of the fortification mix. Previous experience with rice fortification has indicated that before it was generally accepted if the fortification grains were clearly discernible people would pick them out and throw them away. This is a great problem since we would like to put riboflavin in our mixture and up until now all fortification mixture with riboflavin has been yellow. There are some possibilities that in the future this problem may be solved. It is also conceivable to me that once rice fortification is accepted, that the consumer may prefer a colored RFG to make sure that his rice is fortified. In any case in our studies we are not adding riboflavin. Fortunately, in the area in which we are working riboflavin deficiency is not as bad as it is in other parts of Thailand. Nevertheless, the dietary level is not as high as it should be.

In order to do a study of the effects of fortification, we have to make sure that the fortification mixture is getting to all of the people examined. We are going to work and have been working in villages where all of the rice is milled in a single village mill. We have built rice feeders which are attached to the mills and which add the RFG to the rice after it has been milled. In Thailand there are approximately 23,000 rice mills. I feel that it will never be practical, assuming that fortification is desirable and wanted by the government, to install a feeder at every mill. It is conceivable that at some of the larger mills this might be done. Thus, one of the things we will have to look at will be other ways of getting fortification mixtures to the rice. I can think of things that might be done. Ajinimoto in a short period of mass marketing of monosodium glutamate in Thailand has raised the consumption of MSG to 200 gms a person per year. It seems to me that there is a lesson here which might be of value in introducing fortification.

In doing studies with people in developing countries one of the things most often complained about is the appearance of the researcher as an individual who doesn't care about the people but is mainly interested in obtaining the data. We decided that we would like some visible manifestation in the very beginning of our study that we had an interest in the people. We decided that at least in some of our experimental villages we would build day care centers. This would not only provide the villagers with evidence of our interest, but we are also interested in evaluating the day care centers as village institutions

with potential impact on the health and nutritional status of pre-school children. The study, as I will presently describe it to you, is designed so that we can separate out the effect of the nutrient supplement. One of the things that the day care center can do for us is that it may enable us to get some morbidity data which otherwise would be extremely difficult to obtain under the circumstances. We have been keeping an attendance record at our day care centers. When a child is absent, we record whether the child is absent because he is ill or because of other reasons.

We will have five different types of villages in our full field study which will start next month. It will involve 25 villages with a total population of approximately 15,000 and about 2,700 pre-school children. Let me go through the types of villages that we shall have. There will be five raw controls. These will be villages where the only thing that will be done will be a physical examination. We will not introduce either the day care centers or the feeding programs. There will be a set of villages which will receive the day care centers and a placebo RFG. There will be another set of villages which will receive day care centers and a RFG consisting of vitamin A, vitamin B_1, and Iron. There will be another set which will receive the day care centers and a RFG containing the vitamins and minerals and in addition, lysine and threonine. And then there will be a group of villages which will receive the full fortification mixture but without the day care centers.

We will use threonine as well as lysine in the fortification mixture. We had to make a decision as to whether we thought threonine was important or not in a rice fortification program. In rat studies, the evidence is overwhelming that threonine as well as lysine must be added to rice to really raise the biological value of its protein.

Let me tell you something about what we hope to measure. In the initial studies we will be rather dependent on a whole variety of anthropometric studies; things like body weight and length, skin fold, hand wrist x-rays, etc. All pre-school children in the village, whether or not they go to the day care center, will be examined. Obviously, if the mother really doesn't want her child to be examined we would not force them to take the examination. The children will be given a physical examination similar to the type used in nutrition surveys all over the world. We will get some data on morbidity. The laboratory studies being done in pre-school children at this time are hemoglobin, and urinary and nematocrits thiamine creating ratios; the latter mainly as a check on the fortification mixture getting into the rice supply.

We have other checks. Each village will be visited every day, to make sure the RFG are being added properly. Furthermore, we have records of the amounts of rice milled in each mill and the amount of RFG being used. We will also do hemoglobin and hematocrit tests on women of child bearing ages. We shall obtain records of deaths in the villages, and records of births. In these villages it is possible to get birth dates. As we go on, we hope we will be able to develop a methodology for measuring mental and motor development. It is expected that when this work is concluded that we shall be in a much better position to discuss the benefits of rice fortification than we are today.

CORN BREEDING

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The protein of the corn grain falls into two quite distinct groups. The protein of the germ is essentially balanced and has a biological value approaching that of skim-milk. The protein of the endosperm is deficient in two of the essential amino acids, lysine and tryptophan. Feeding trials with monogastric animals indicate little gain from amino acid supplementation unless both of these essential acids are supplied. The alcohol soluble fraction, zein, contains very little of these amino acids and it is this fraction that is most influenced in selection for increased protein level.

In 1964, Dr. Mertz and his associates at Purdue reported that opaque$_2$, a well known mutant in corn, was characterized by a drastically altered amino-acid profile. At a later date, another mutant, floury$_2$, was shown to condition the same general changes in amino acid composition. These two mutant types have come to be commonly known as 'high lysine' corn. This terminology is perhaps unfortunate since tryptophan content is modified as drastically as is lysine and several other amino acids are involved. These two mutants, opaque$_2$ and floury$_2$, transform the protein inadequacies of normal corn protein into protein which has a biological efficiency only slightly less than that of skim-milk. Several people who were involved in this demonstration are in the audience and I shall defer to them for further expansion of the topic of nutritional adequacy.

On the report of this new finding many persons saw the potential benefits of the new type both as human food and as feed for monogastric animals. Since the two genes had previously been reported as simply inherited recessives it appeared that a simple backcrossing procedure would be adequate to transfer one or both of these genes into any desired genotype. Extensive work along these lines was undertaken by the private seed companies and the public agencies. The usual procedure was to cross opaque$_2$ and a series of standard lines. These were advanced to the F_2 generation and opaque$_2$ seeds recovered from the F_2 ears exhibiting the clearest segregation. Such kernels were then used as parents for the next cycle of backcrossing. Using this process, opaque$_2$ versions of a large number of standard lines have been obtained. When these have been used to produce single crosses and compared with their normal counterparts, the yield results in the United States have been disappointing.

Breeding work has been pushed forward as rapidly as possible using two generations per year. Apparently more success has been achieved in the high lysine program in Colombia where three generations per year have been possible. I do not have comparative yields from the Colombian program but in the United States the best of the opaque$_2$ single crosses have yielded no more than 90–95 percent of their normal counterparts and most have yielded much less. Unless this yield disparity can be overcome the 'high lysine' hybrids will not be acceptable to U.S. farmers.

Several problems appear to be involved; all related to the floury texture of opaque$_2$. Specific gravity tends to be low, giving a reduced 100 kernel weight. Soft kernel types tend to be more susceptible to ear rots than either dent or flint types. They are also more susceptible to stored grain pests where these are a problem. Floury kernel types also tend to dry more slowly than their normal textured counterparts. In varying degrees each of these factors has contributed to the lower yield or the reduced acceptability of the hybrids thus far evaluated.

In my opinion, the foregoing should not be interpreted as indicating that satisfactory high lysine hybrids cannot be developed; rather it is an indication of the inadequacies of the methods used.

Opaque$_2$, like most simply inherited traits, is subject to some degree of modification by minor genes. In the case of opaque$_2$, this susceptibility to modification was first observed in genetic studies; some F_2s were easy to classify, others more difficult. The influence of modifiers was also reported by Alexander at the time of the High Lysine Conference. In some inbred backgrounds, opaque$_2$ kernals weighed only 60 percent of their normal counterparts; in other lines the comparisons were in the range of 90:100. Opportunity for selection during backcrossing was quite limited due to the re-introduction in each generation of the constant recurrent parent genotype.

There is some evidence that modifying factors also influence the amino-acid profile. Recovered lines may not exhibit the same desirable amino-acid balance as the original opaque$_2$ stock. Whether these deviations represent two independent modifier systems is not clear, but at least some of the near normal density opaque$_2$ segregants have reduced lysine and tryptophan contents. Where endosperm texture plays a controlling role in acceptability, less reliance must be placed on phenotypic classification and more on amino-acid analyses.

The short-term breeding procedure, the incorporation of opaque$_2$ or floury$_2$ into standard inbred lines although not highly successful to date, is being continued. Several longer-term alternatives are being explored. The first step, in each case, is the introduction of opaque$_2$ into broad based populations. Subsequent procedural details vary and I shall consider only the broader outlines. In Illinois selection pressure is being applied to lysine composition using a microbial assay. The work in Iowa is less advanced but they propose exploring several possibilities. Current information is quite inadequate on the most efficient procedure for handling several variables simultaneously. Sequential selection or use of a selection index are two obvious possibilities. Choice between these or other selection procedures is dependent upon the inter-relations of importance. Accordingly, parallel studies will involve holding yield or protein percentage constant and determining relative rates of progress for lysine percentage. Studies are also underway exploring the relation between kernel density and lysine percentage.

Extensive nutritional studies with children in both Guatemala and Colombia have amply demonstrated the biological value of high lysine corn. It has also been demonstrated for these same areas that the product is locally acceptable. Nutritional gains, however, are dependent upon local practices in food preparation. It is expected that the full-protein improvement would be retained under any system of food preparation which involves utilization of the entire grain, minus the pericarp, whether this involves use of the product as a gruel masa or tortillas. With some other methods of preparation, however, much of

the improvement in protein quality may be lost. In parts of Nigeria and Malawi, corn is prepared for food by a crude process simulating wet milling. This involves pericarp and germ removal, and grinding with water to reduce particle size. In consequence, valuable protein is lost and the final product is primarily starch. Studies by home economists in Nigeria have indicated that minor changes in manner of preparation are feasible which will retain much of the improved protein quality. Since the preparation of "Oge" is more of a village than a home activity there is some hope that improvements in methods of preparation may be adopted.

In southern Nigeria, in Uganda, and in similar ecological areas, a substantial portion of the corn crop is eaten in the green or immature stage. When eaten in this manner full benefit could be derived from the improved amino acid composition. Some of the crop, however, is stored and the mature grain utilized. The necessity for storage imposes special problems in the lowland tropical areas.

The special problems encountered are illustrated by the experience with the white opaque$_2$ synthetic recently released in Nigeria. In this case, the opaque$_2$ characteristic was introduced into a synthetic by the usual backcrossing procedure. Selection in each cycle was from F_2 ears exhibiting the most clear-cut segregations. After three generations of backcrossing, opaque$_2$ kernels were bulked and the increase from this bulk formed the new opaque$_2$ synthetic. The yield of this synthetic was equal to or better than the locally grown flour type Lagos White.

Acceptance of this new type, however, has been less than anticipated. This synthetic has poor to average husk protection and therefore sustains a greater than normal field infestation of weevils and moths. In the absence of proper storage conditions, the resulting loss after two or three months is quite great. Unless this disadvantage can be overcome either by breeding or improved storage conditions this synthetic will never achieve more than limited usage.

This discussion of high lysine corn types may appear rather discouraging. It is, however, realistic. Two points appear to be quite clear. First the nutritional gains to be derived from the use of high lysine corn are very significant and potentially of great importance. Second, the breeding problems are much greater and more difficult of solution than one would presume from the knowledge that the trait is simply inherited. The combination of this trait with all other genetic factors required to achieve yield comparability and farmer acceptance presents a difficult problem for the breeders. The potential value of the crop is sufficiently great, however, that these problems will eventually be solved.

HIGH LYSINE CORN: PROBLEMS OF UTILIZATION

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Two facts stand out in any consideration of the problems of utilizing high lysine corn:

1. High lysine corn has only one reason for being considered–its protein quality is significantly better than that of normal corn.

2. High lysine corn's greatest potential humanitarian value is in decreasing or overcoming malnutrition among the very poor in rural and urban areas in countries where these people consume high per capita quantities of corn.

In order to assess problems and opportunities and whether high lysine corn may achieve an important role in overcoming malnutrition, we need to consider:

a. The economic aspects of crops.
b. The problems in getting farmers to grow high lysine corn.
c. The marketing and distribution problems.
d. The possible impact of animal feeding on high lysine corn demand.
e. Processing requirements and problems they pose.
f. Use of high lysine corn in foods.
g. The real nutritional values of high lysine corn and can they be sold to those who most need them.

The Economic Aspects of Crops

There seems to be a growing body of information showing that high lysine corn poses no unusual problems in planting, cultivating, and harvesting. If first cross seeds properly selected for the areas are used, based on field trials in the United States, yields appear to be almost equal to normal corn on a volume basis but the bulk density of high lysine corn is lower causing an overall average differency by weight of 6 to 8 percent. This is a field cost penalty which the crop must bear until genetic improvements under development can decrease the yield difference. There are wide variations in yield from farm to farm but so are there with normal corn. In parallel plantings, high lysine corn and normal corn yields generally vary to about the same extent from farm to farm. Of course, the wide difference in yields from country to country and from farm to farm within a country result in major differences in the price of corn in the numerous countries in which it is grown.

The Problems in Getting Farmers to Grow High Lysine Corn

In developing countries many farmers are very poor. They seldom have much formal education. Their crop often is their major food source. Even if these farmers have enough

land to produce in excess of their needs, they depend heavily on corn for food and the small income they get. A new, untried crop (to them) poses a threat to their family's very existence. It is not surprising that these farmers resist efforts to get them to plant a new type corn. Even if they do agree to plant high lysine corn on some of their land, the farmers must buy seed as opposed to using kernels from their previous crop as seed. As a result, it is often necessary to guarantee a premium over normal corn of as much as 15 to 20 percent to get them to agree to grow high lysine corn. This adds to its cost and results in a field price of 115 to 120 percent of normal corn.

Marketing and Distribution Problems

Normal corn moves through commodity distribution systems which vary in complexity from country to country. Normal corn, not consumed on the farm, can be taken by a farmer to a local elevator. It moves along with other corn to larger elevators in the cities and from there is purchased by processors. It is essentially a single grade which need not be specially handled. A processor needing corn buys the corn stored in the elevator. Storage and handling costs are minimized. Contrarily, high lysine corn must be segregated and kept apart from normal corn on the farm, in local and urban elevators and in transportation systems. This can add about $3.50/ton to the cost for up to four months storage and another 50¢/ton for each month thereafter. Assuming normal corn at $80/ton field price, the comparable field price for high lysine corn would be $92-$96/ton and the price of the processor would be $110-$115/ton vs. $95/ton for normal corn--a premium of 16 to 21 percent for high lysine corn.' Evidently, this poses problems for the processor.

It might be argued that one should fortify normal corn instead of growing and processing high lysine corn. It is interesting to compare costs. If the added lysine and tryptophan were put into normal corn to bring these amino acids to the same level as in high lysine corn, and if the differences in protein contents are adjusted, the following table shows the cost comparison:

	Cost to Processor-$/T	L-Lysine[1] Required-g.	DL-Tryptophan[1] Required-g.	Cost of Corn Fortified[5]		
				Market[2]	Current[3]	Projected[4]
Normal Corn	95	2205	525	152.90	127.60	114.15
High Lysine Corn	115	0	0	115.0	115.0	115.0

[1] Based on normal corn at 9.4% protein (as is) and high lysine corn at 10.5% protein (as is). Normal corn at 2.7 g. lysine/100 g. protein and high lysine corn at 4.8 g. lysine/100 g. protein. Normal corn at 0.7 g. tryptophan/100 g. protein and high lysine corn at 1.2 g. tryptophan/100 g. protein.

[2] L-Lysine @ $1.95/#in 100#drums; DL-Tryptophan @ $90.00/kg. in 100 kg. lots; from Oil, Paint & Drug Reporter, November 23, 1970.

[3] L-Lysine @ $4.00/kg. in 100 kg. lots; DL-Tryptophan @ $24.00/kg. in 100 kg. lots; from recent quote from Ajinomoto Company of New York, Inc.

[4] Altschul, Aaron M., "Amino Acid Fortification of Foods", Third International Conference of Science and Technology, August 9-14, 1970, Table II, "The assumed prices per lb. for amino acids are as follows: L-lysine $1; L-threonine $8.50 and $3; DL-tryptophan $5.90."

[5] Based on quantity of corn required to give equal protein contents in normal corn and high lysine corn and equal quantities of lysine and tryptophan. High lysine corn cost per ton.

The likelihood and timing for achieving the projected synthetic amino acid costs must be considered in the light of probable reductions in the cost of high lysine corn as genetic improvements are made and farmer confidence grows. This leaves open the question of the relative nutritional merits of all natural amino acids vs. part natural and part synthetic amino acids.

Possible Impact of Animal Feeding on High Lysine Corn Demand

Apart from its value in human feeding, high lysine corn offers opportunities for improving the nutrition of animals. Cattle will gain no benefits from eating high lysine corn as compared with normal corn. Poultry may receive added benefits but this has not been quantified commercially. Swine do receive added benefit from high lysine corn and this has been measured both in Colombia and the United States. In tests conducted by practical farmers on over twenty farms in the United States earlier this year, high lysine corn cut the cost of raising swine from weanling pigs through finishing the swine for market. An average benefit of 1¢ per pound of weight gain was achieved for high lysine corn. This means about $2 per hog gain for the farmer.

We are not here to discuss animal feeding but it may become an important factor in encouraging farmers to grow high lysine corn and eventually in lowering its cost. Both these contributions would make more high lysine corn available for those who need it most.

Processing Requirements and Problems They Pose

Nothing is to be gained in wet milling high lysine corn for producing food ingredients. In fact, it is expected that processing yields will be less favorable apart from the higher corn cost. Dry milling is the preferred approach but the floury character of the high lysine corn endosperm shifts the output toward smaller particle sizes with more flour and less grits. This is in the direction of lower sales value. Hence, a higher price corn produces an output having lower sales value as food ingredients.

As stated initially, the only reason for growing high lysine corn is its high protein quality. Flour and grits from a dry mill contain only about half the protein in the kernel. The remainder is in the germ, hull, and other parts going into animal feed. Since recovery of protein is the major objective, other approaches than dry milling may be required to improve the attractiveness of high lysine corn. Even so, new problems will be introduced re the economics of such processing systems, the value of the new output mix, and the composition of the separate streams in relation to their acceptability for food needs.

Use of High Lysine Corn in Foods

High lysine corn can be used in any foods that normal corn can be used in, giving due consideration to the smaller grit structures of the endosperm. If farmers grow high lysine corn for their own use, they should face no unusual problems in using it as they do normal corn. The same comment applies to those in small towns and urban areas

who buy corn and have it milled for their use. A different problem faces the processor. If he markets foods from high lysine corn duplicating those already on the market from normal corn, he offers a product with better nutrition but his higher raw material costs force him to price his product higher than his competitor's product and it is questionable whether low income groups can be induced to pay higher prices for nutrition only. This leaves new, fabricated products as the only ones which may have a chance of competing. It places a premium on imagination, marketing skills, and the added costs of educating lower income groups to buy new products.

It might be argued that high lysine corn protein is expensive when compared with other plant proteins. It is, if only the protein is considered. At 10.5 percent protein and $115 per ton, protein costs $1.085 per kg as compared with soybeans at 40 percent protein and $175 per ton or 43.6¢ per kg. of protein. However, the oil and carbohydrate in high lysine corn have value as nutrients. The oil may be included in products or it may be separated from the endosperm and yield a good return when sold as refined oil. Also, consumer acceptance of corn is usually much higher than soybeans. Therefore, the two raw materials have to be compared taking into consideration consumer acceptance, and all the nutrients they provide, and their separate values.

If one could process high lysine corn in a manner to recover all three nutrients, and then control the relation of protein and carbohydrate contents through processing, almost an ideal balance of the three nutrients could be achieved while providing calorie and protein levels desired.

The Real Nutritional Values of High Lysine Corn and Can They Be Sold To Those Who Need Them?

High lysine corn is slightly higher in protein and fat contents and lower in carbohydrate content. Mineral matter is about the same and fiber content is somewhat higher. Field moisture and moisture in storage tends to be somewhat higher. Its protein has an amino acid profile more closely approximating desired patterns such as the FAO Provisional Pattern, mother's milk, and stated requirements for infants such as those set forth by Holt and Snyderman in 1961. Biological Value, Net Protein Utilization and Digestibility of high lysine corn protein are all much higher than those for normal corn. In fact, they compare favorably with those for cow's milk. Certainly, high lysine corn protein has higher quality than any other conventional plant protein.

While dramatic results have been achieved with high lysine corn protein in overcoming malnutrition in young children, and while it can be shown that heavy corn consumers can overcome malnutrition just by changing from normal corn to high lysine corn, there still remains the open question, "Can better nutrition be sold to consumers who have free choice in the market in products at higher price but without other *apparent* advantages?" There is some evidence that this is possible but entirely too little to draw any conclusions. There needs to be many more examples before the techniques can be understood well enough to state with reasonable certainty how to achieve this goal, how much it costs, and is it really worth the cost.

Major Problems and Questions

In conclusion, the following problems and questions are cited:

1. How can farmers be induced to grow high lysine corn for their families' needs and for feeding their swine?

2. How can seed be made available to farmers as one inducement?

3. How can high lysine corn be put into distribution in stores in towns and cities so that those living off farms while still consuming large quantities of corn can gain its benefits?

4. How can the burden of higher raw material costs be reduced as a means of making it possible to get more products containing high lysine corn to those in urban areas?

IMPROVEMENT OF CORN PROTEIN QUALITY

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An analysis of the available experimental information on cereal grain protein and its nutritive value indicates that, 1) as a class, cereal proteins are low in lysine and many are also low in one or more of the other essential amino acids; 2) addition of the deficient amino acid(s) improves the quality of the protein but very seldom to the quality found in animal protein sources; 3) this indicates that the essential amino acid pattern of cereal proteins deviates from the ideal pattern, that is, they have, besides deficiencies, excess of some essential amino acids which decrease the efficiency of biological utilization and 4) cereal proteins contain lower amounts of most of the essential amino acids than animal proteins.

With respect to corn proteins, the deficiency in lysine and tryptophan were first known about 65 years ago, and the information obtained since then has confirmed the existence of such deficiencies as well as the existence of imbalances, the best example of which is that of leucine.

Most of the evidence of the lysine and tryptophan deficiencies in corn proteins has come from studies in experimental animals. There is, however, some information from human subjects, both children and adults. Figure 1 of this summary show data from children fed various levels of corn as the sole source of protein, with and without lysine and tryptophan supplementation. The effect is compared to the response obtained with milk fed at equal levels of protein intake. The results indicate: 1) that there is need to feed 3 g of protein/kg/day of unsupplemented corn to obtain positive nitrogen balance, this level of protein is equivalent to about 38 g of corn (8 percent protein) per kg body weight per day. 2) The addition of lysine and tryptophan improved nitrogen utilization, the extent of which is directly related to protein intake. 3) Only at high protein intake does the addition of the two amino acids improve protein utilization to values similar to milk. 4) The figure also shows the high quality of opaque-2 corn protein, which, even at an intake of 1.5 g protein/kg/day, gave nitrogen retention values close to those obtained from milk. The protein level of intake of 1.5 g protein is equivalent to approximately 14 g of corn/kg/day. These data show that protein utilization is significantly increased by amino acid addition, however, the quality obtained is not that of milk or opaque-2 corn protein. The high retentions with opaque-2 corn may be interpreted on the basis of its higher levels of lysine and tryptophan and better over all essential amino acid pattern than that found in common corn.

The children data was used to project the findings into practical terms. These calculations are shown in Table 1. Since the needs for energy rank second only to the need for water, the table shows as an example the amount of corn needed to meet the requirements for calories in children 2, 6, and 10 years of age. Corn in Central America contains approximately 8 percent protein and on this basis the amount of corn meeting the needs for calories provide 24.8, 36.1, and 45.0 g of protein for respective age groups. From the children nitrogen balance data, the biological value of unsupplemented and supplemented corn was calculated to be 32 and 55 percent respectively. Using these figures, it is possible to calculate utilizable protein. These values for unsupplemented corn are 7.9, 11.5 and 14.4 g for 2, 6, and 10 year old children, figures which are lower than the protein needs for each age group. On the other hand, lysine and tryptophan supplemented corn provides 13.6, 19.8, and 24.7 g of utilizable protein. Although these calculations project the data into practical terms, it should be pointed out that in the first place it is almost impossible for a 2, 6, or 10 year old child to consume 310, 451, or 563 g of corn. It is possible, however, to consume about a third of these amounts. This means lower intake of nitrogen and therefore, a lower benefit from amino acid supplementation. Nutritional surveys from Guatemala show 4-5 year old children consume around 130 g of corn. Table 2 show some calculations on utilizable protein from common corn plus lysine and tryptophan, and opaque-2 corn. The biological values were calculated from the children data shown before. Addition of the amino acidds increased protein utilization from 3.3 g to 5.7 g. Better utilization resulted from opaque-2 corn. This was due to

Table 1. Protein Utilization in Children Fed Corn Without and With Lysine and Tryptophan

	Age (yr) and Weight (kg)		
	2 yr, 12.3 kg.	6 yr, 20.5 kg.	10 yr, 30.5 kg.
Daily calorie requirement (I)	1100	1600	2000
Corn needed to meet (I)[1] (II)	310 g	451 g	563 g
Protein derived from (II)[2] (III)	24.8 g	36.1 g	45.0 g
Minimum protein requirement[3] (IV)	14.8 g	15.4 g	21.3 g
Utilizable protein from corn[4] (V)	7.9 g	11.5 g	14.4 g
Utilizable protein from Lysine and Tryptophan fortified corn[5] (VI)	13.6 g	19.8 g	24.7 g

[1] Calories in 100 g of corn: 355
[2] Protein in 100 g of corn: 8
[3] Protein with B.V. of 100%
[4] B.V. of unsupplemented corn: 32%
[5] B.V. of unsupplemented corn: 55%

Table 2. Protein Utilization in Children Fed Common and Opaque-2 Corn

	Common corn	common corn + Lys + Try	opaque-2 corn
Corn intake g/day for 5 yr old children in Guatemala	130	130	130
Protein intake from corn, g	10.4*	10.4*	13.4**
Minimum protein reg, g***	15.4	15.4	15.4
Biological value, %	32	55	69
Utilizable protein, g	3.3	5.7	9.2

* Protein content, 8%
** Protein content, 10.3%
*** Biological Value of 100 %

both higher protein content and protein quality. It would appear, therefore, that corn protein utilization would increase if its total nitrogen content were higher.

Table 3 summarizes representative results of studies performed with rats to find a practical way to improve corn protein quality in Central America. These data show, as before, that amino acid supplements, or a supplement consisting of soybean flour plus lysine, improve the protein quality of corn as judged by the higher PER values of the supplemented corn diets. The nutritive value of the protein relative to that of casein also improves as well as the percentage of utilizable protein. These data also seem to prove that higher protein content in corn, as represented by the corn supplemented with soya flour and lysine, increases utilizable protein over that obtained from amino acid addition alone. Further evidence in this respect is shown by opaque-2 corn which, because of its high quality as well as its higher protein content, gave together higher percentages of utilizable protein.

Many authors apparently do not realize that corn or any other cereal grain for that matter is not consumed alone. Because the accompanying foods usually provide protein and therefore amino acids it is important to test the effects of supplementation of corn or other cereals in diets as consumed by people. Attempts to measure the benefits of supplemented corn in corn-bean diets are shown in Table 4. In this representative table, adult dogs were used giving high nitrogen retention values with the basal diet. Nitrogen retention improved by the addition of lysine and tryptophan to corn, or by replacing common corn with opaque-2 corn. Similar studies for young animals are shown in Table 5. In this case, protein intake was 2.5 g/protein /kg/day, and on the basal diet, retention of

Table 3. Supplementation of Lime-Treated Corn upon the Nutritive Value of the Protein

Protein	Protein, %	PER	Relative nutritive value, %**	Utilizable protein, %
Corn*	7.9	1.26	33.7	2.66
Corn* + 0.3% Lys + 0.1% Try	8.0	2.78	74.5	5.96
Corn* + Soy flour + 0.1% Lys	9.7	2.43	65.1	6.31
Casein	9.8	2.80	75.0	7.35
Opaque-2 corn*	10.1	2.66	71.2	7.19

* Lime-treated
** % Relative Nutritive Value to casein

Table 4. Nitrogen Balance of Adult Dogs Fed a Corn-Bean Diet With and Without Amino Acid Supplement

Treatment to Basal diet*	Nitrogen Balance mg/kg/day				
	Intake	Faecal	Urine	Absorbed	Retained
Common corn	375	121	155	254	99
Common corn** + Lys + Try	374	116	118	258	140
Common corn**	356	117	151	239	88
Opaque-2 corn**	385	124	122	261	139

Average: 4 dogs
* Basal diet: 82.8% corn + 10.5% beans + 6.7% other nutrients
** Lime-treated corn

Table 5. Nitrogen Balance of Young Dogs Fed a Corn-Bean Diet With and Without Amino Acid Supplement

Treatment to Basal diet*	Nitrogen Balance mg/kg/day				
	Intake	Faecal	Urine	Absorbed	Retained
Common corn**	399	152	206	247	41
Common corn** + Lys + Try	374	156	143	218	75
Common corn**	357***	157	165	200	35
Opaque-2 corn**	407	165	127	242	115

Average: 6 dogs
* Basal diet: 82.8% corn + 10.5% beans + 6.7% other nutrients
** Lime-treated corn
*** Diet was not consumed completely

nitrogen was lower than for the adult animal, as shown in the previous table. Supplementation with lysine and tryptophan improved nitrogen utilization, but better values resulted from the opaque-2 corn-bean diet.

It is of interest to indicate that on the common corn-bean diet some of the animals were not able to consume the weight of diet equivalent to 2.5 g of protein/kg/day, due to the bulk of the diet as well as to its poorer quality.

Both of those studies show that supplemented corn is of benefit in improving the quality of the mixed diet, but better utilization of the protein is obtained with adult animals than with young ones. The reason probably lies on the fact that higher levels of protein are needed for the young animal which are difficult to provide with present concentration of protein in corn.

To emphasize the point, the results in Table 6 are presented. Addition of lysine and tryptophan to common corn in the corn-bean diet improved nitrogen utilization at a level of intake of 2 g of protein/kg body weight/day. The increase was from 28 to 76 mg nitrogen retained.

TABLE 6
NITROGEN BALANCE OF YOUNG DOGS FED A CORN-BEAN DIET WITH AND WITHOUT VARIOUS SUPPLEMENTS

Treatment to Basal diet	Protein intake g/kg/day	Nitrogen Balance mg/dg/day					Retent. % of intake
		Intake	Faecal	Urine	Absorbed	Retained	
Common corn	2	311	137	146	174	28	9.0
+ Lys + Try	2	321	138	107	183	76	23.7
+ Non-specific N	2+1	472	147	244	325	81	17.2
+ Lys + Try + NsN	2+1	475	141	196	334	138	29.0
+ Protein	2+1	457	142	141	315	174	38.1

Average of 12 animals

When the basal diet of common corn and beans was supplemented with a source of non-specific nitrogen to provide together 3 g of protein/kg/day, nitrogen retention was practically the same as that obtained from lysine and tryptophan addition to corn used in the mixed diet and fed at a level of 2 g protein/kg/day. However, utilization of the protein was not as high, as indicated by percentage nitrogen retention, which dropped from 23.7 to 17.2 percent. It was however about twice as high as that from the basal diet alone fed at 2 g of protein per day. Better performance resulted when the supplements were lysine, tryptophan, and non-specific nitrogen which increased nitrogen retention and nitrogen utilization over the values obtained with the previous diets. Even better performance was obtained when the supplement was a protein as shown by the last line.

These results were interpreted to mean, as was already suggested, that corn protein quality could induce greater benefits if it contained higher concentration of protein. Therefore, if practical. benefits are expected from amino acid fortification of cereal grains, it is necessary to find the means of increasing protein intake either by using cereal grains with higher protein content or supplements which will supply not only the deficient amino acids but also additional nitrogen or protein as well.

Consideration should be given to other nutrients as well.

To emphasize this point, the results of Table 7 are presented. They show that the benefits of lysine and tryptophan added to corn are obtained only when other essential nutrients are added as well.

TABLE 7
EFFECT OF VARIOUS SUPPLEMENTS ON THE NUTRITIVE VALUE OF A CORN-BEAN DIET

Diet	Average weight gain, g**	PER
Basal	26 ± 2.35	1.09 ± 0.07
Basal + AA + Vit	26 ± 2.52	1.10 ± 0.08
Basal + AA + Vit	54 ± 3.92	1.73 ± 0.08
Basal + AA + Min	89 ± 3.35	2.37 ± 0.06
Basal + AA + Min + Vit	107 ± 5.00	2.55 ± 0.06

* Corn-bean Basal: corn, 724% ; Beans, 8.1% ; sugar, 138% ; roots, 5. %
(9.1% protein, 374 cal/100 g)

** Average initial weight: 44 g

In the example shown, the presence of vitamins and minerals were essential before a definite response was obtained from lysine and tryptophan supplementation. Again, these date point out that addition of amino acids alone to improve poor quality cereals in diets is not enough. Fortifying mixtures should contain all the nutrients needed for the efficient utilization of an improved amino acid pattern. This, in turn, will demand higher intakes of other nutrients.

Amino acid fortification is a complex problem with many implications; however, there is no doubt that if properly carried out, it could have tremendous benefits for mankind.

CORN FORTIFICATION–RECOMMENDED ACTIONS

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The agenda requested that I speak to the question of recommended actions in the field of corn fortification.

I would like to approach this problem in the light of the paper Dr. Ricardo Bressani has given and in the context of the problem as it pertains to corn eating countries. In the total scheme of national development in any country, there are a number of key areas which can affect human resource development. Given that considerable and very valid data exists indicating that this human resource is compromised by the existence of malnutrition, in particular protein calorie malnutrition, and is further stressed by public health problems, with high incidence of mortality and morbidity from infections and a concomitant low educational performance, a national development scheme has three areas which it may emphasize: education, public health and nutrition intervention.

Existing data demonstrates with very little reservation that efforts to promote education, i.e. increase the literacy of a developing people, can be severely constrained by apathy and disease and, in particular, protein malnutrition while "in utero" or during infancy. Data also exists to show that efforts to increase the quality of the public health through sanitation and innoculation schemes, as well as other preventive medicine procedures, does not invariably increase the *quality* of the human resource even though it may occasionally increase the life span of these individuals and even decrease the incidence of diseases. In other words, the public health procedures decrease the incidence of insults to the human resource in question, however, these procedures do very little for the biochemistry of the human resourse *per se* and thus his behavioral and educational performance. Further, we know that a nutrition intervention based on the provision of supplements which are not a part of the diet habits of the people are of limited usefulness in many respects. Further, nutritional interventions with supplements very often fail to reach the critical individuals i.e. the mothers during pregnancy and the child during lactation and immediately after weaning.

Now if one considers a corn eating country in which the diet is substantially corn, i.e. provides 70–80% of the daily calories and protein, it follows that a significant nutrition intervention could possibly occur through the manipulation of this important food in the diet, hopefully without incurring any change in the dietary habits of the people. There are two major approaches available for the nutritional improvement of corn:

(1) The use of a corn which would have a higher concentration of quality protein such as the high lysine strains of corn.

(2) Fortification of the existing corn by the addition of additional protein and the limiting amino acid(s).