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THE WORLD PROTEIN AND NUTRITIONAL SITUATION

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Abstract

THE WORLD PROTEIN AND NUTRITIONAL SITUATION.

The world protein and nutritional situation is dependent on complex interactions between the adequacy of food production in quantity and quality, socio-economic conditions, stability of supplies, country and within-family distribution, costs, population growth and government policies. The main nutritional deficiencies affecting populations in developing countries include the controversial but real protein-calorie deficiency, anaemias, goitre and vitamin-A deficiency. Thus, various nutrients are simultaneously responsible for the malnutrition problem. The diet must, therefore, provide nutrients as a group whose utilization and function are closely interrelated, and the balance of a diet has a profound influence on appetite, nutritional adequacy and health. Within this context protein quantity plays an important role. The experimental evidence of this now available is overwhelming. The paper discusses problems of protein quality with respect to food availability in amount and frequency of intake, the interaction with other nutrients on food intake and with bulk and environment. The role of improved protein quality of staple foods in diets is also discussed. Finally, arguments are presented that agricultural productivity must include, in addition to yield, technological and nutritional qualities. Based on a long series of studies and with a view to increased interaction between plant breeders and nutrionists, nutritional standards for some basic staples are proposed. Based on the information presented, the paper supports the thesis that efforts must continue towards improving the protein quality of basic food items and diets.

INTRODUCTION

It is well recognized that more than a third of the world's population suffers from serious malnutrition. Recent World Bank figures indicate that the annual income in about 36 less-developed nations is about $265 per person and in another 34 the figure remains as low as $520. These figures point out the extreme poverty existing in these nations. Income alone, however, does not explain the extent of hunger and malnutrition in developing countries and a more detailed analysis indicates that the situation is dependent on complex interactions among various factors such as the adequacy of food production in quantity and quality, the extent of poverty or socio-economic conditions, stability of food supplies, distribution and prices, rate of population growth and government policies.

The interaction of these and other factors results in an inadequate diet for people in the developing countries where the lack of a variety of nutrients plays a role. The main nutritional deficiencies affecting populations in developing countries include the controversial but real protein-calorie deficiency, anaemias generally due to iron deficiency, goitre resulting from the lack of iodine, and vitamin-A deficiency. From these facts it is concluded that various nutrients are simultaneously responsible for the malnutrition problem, including energy and protein. In recent times the problem of the 'protein gap' has been questioned with respect to the world nutrition situation, and it has been argued that energy intake or food intake is a larger problem within the nutrition situation of vulnerable population groups in developing countries. Nutrition, however, is not individual nutrients alone, but rather a group of nutrients whose utilization and function are closely interrelated and the balance existing in a food item or diet has a profound influence on appetite, nutritional adequacy and health. Within this context protein quantity, and more especially protein quality, play an important role. The practical significance of protein quality in food crops may be considered from two points of view. One is the direct impact it can have in terms of nutrition and health. The second is more related to the efficiency of utilizing resources, including energy, to produce more but with better technological and nutrition properties.

The object of this presentation is, therefore, to provide arguments to support the thesis that efforts must continue to be made towards improving the protein quality of basic food items and diets.

THE SIGNIFICANCE OF CAUSAL FACTORS IN MALNUTRITION

As already pointed out, the malnutrition problem is the end result of the complex interaction of various factors. For the purposes of this presentation the nutrition component alone, in terms of the significance of factors such as quantity of food available and frequency of intake, the effect of quality of protein and other nutrients on food intake, the role of bulk and other factors, will be discussed. These indicate the need for research into producing high protein quality cereal grains, increases in bean production and quality, fortification programmes and the development of weaning or special-type foods.

Low food availability

Amount

Food availability is probably one of the most important factors in nutrition. The causes may be varied, starting with low production, poor and inefficient handling and storage, lack of distribution systems and high cost. These conditions

TABLE I. PROTEIN QUALITY OF CORN-BEAN MIXTURES

Food	NPR
Corn (100%)	2.31
Corn (90%) + beans (10%)	2.78
Corn (70%) + beans (30%)	3.52
Beans (100%)	2.29
Casein	5.08

exert pressure on the whole population and particularly on the most vulnerable groups. The significance of this will be shown in the following. Table I indicates that as the amount of legume foods increases in a cereal-bean mixture the quality of the protein ingested increases. Since beans contain about twice as much protein as corn, a higher bean intake also means a higher protein intake. The best combination in terms of nutritive value appears to be that in which corn/bean intake by weight is 2.6 to 1 [1, 2]. Nutritional surveys show that the average corn/bean ratio varies from 7 14 corn to 1 of beans, as shown in Table II, ratios which for various reasons are not as effective nutritionally as the optimum ratio [3]. This low intake of beans is due to its high cost, which is at least 3.5 times higher than the cost of the cereal grain, and to other factors in beans that tend to decrease intake. Recent studies conducted in Guatemala with human populations, shown in Table III, indicate that if beans become available, there is a tendency to shift from a poor ratio to a better one, although not to the optimum [4]. A shift from no beans to increasing amounts results in an increase in the quantity and quality of the protein consumed.

Frequency

Low food availability has obviously a significant influence on the frequency with which food items are consumed. In turn, frequency may influence the nutritive value of the diet. Some results on bean intake frequency are shown in Table IV. These data indicate that bean consumption is low among populations in the low income bracket, which is more important in children who are fed only small amounts when available [3].

The influence of frequency on animal performance is shown in Table V. In this experiment beans and corn were offered in separate feeders for 12, 20 and 28 days for a total experimental period of 28 days in one set of experimental

TABLE II. DAILY CORN AND BEANS INTAKE IN VARIOUS COUNTRIES IN CENTRAL AMERICA [3]

Country	Corn (g/person · d)	Beans (g/person · d)	Corn/bean ratio
Guatemala			
Adults	423	58	7.3
Children	281	24	11.7
Honduras			
Adults	398	56	7.1
El Salvador			
Adults	374	60	6.2
Best nutritional intake ratio	72	28	2.6

TABLE III. CORN AND BEAN RATIOS IN EXPERIMENTAL AND CONTROL POPULATIONS [4]

	Experimental				Control			
	Phase I		Phase II		Phase I		Phase II	
Groups	Corn	Beans	Corn	Beans	Corn	Beans	Corn	Beans
Men	93.7	6.3	89.4	10.6	95.8	4.2	96.2	3.8
Women	93.1	6.9	89.0	11.0	94.3	5.7	94.9	5.1
Children less than 24 months	93.9	6.1	87.1	12.9	95.6	4.4	91.3	8.7
Children 24 47 months	92.3	7.7	88.0	12.0	92.5	7.5	93.7	6.3
Children 48–72 months	94.1	5.9	89.9	10.1	92.9	7.1	93.5	6.5
All groups combined	93.4	6.6	88.7	11.3	94.2	5.8	93.9	6.1

TABLE IV. BEAN INTAKE FREQUENCY PER FAMILY IN RURAL GUATEMALA [3]

Frequency (d/week)	Number of families	Percentage distribution
2	10	12.7
3	20	25.3
4	36	45.5
5	10	12.7
6	3	3.8

TABLE V. FREQUENCY OF BEAN INTAKE ON A BASAL DIET OF CORN AND ANIMAL PERFORMANCE

Frequency of bean intake	Corn + beans fed separately		Corn + beans fed together[a]	
	Ave. weight gain (g)	Carcass N (g)	Ave. weight gain (g)	Carcass N (g)
Corn alone	46	2.47	44	2.54
For 12 days	74	3.17	105	4.48
For 20 days	75	3.23	103	4.51
For 28 days[b]	103	4.02	103	4.45

[a] Using the ratio determined by the number of days in which beans were offered.
[b] Total experimental period: 28 days.

animals, while in the other the ratios resulting from the first set were fed mixed for 28 days. The results from the first set indicate that a higher frequency improves performance in terms of weight gain and carcass nitrogen. Of more practical interest, however, are the findings of the second set, which suggest that small amounts of beans on a continuous basis are sufficient to ensure better nutrition.

TABLE VI. EFFECT OF FREQUENCY OF SUPPLEMENTATION OF A CORN/BEAN (90/10) DIET WITH DIFFERENT LEVELS OF MILK [5]

Amount given	Frequency (d)	Basic diet consumed (g)	Average weight gain (g)	PER
0	0	344	52.9 ± 2.3	1.72 ± 0.05
2	5	386	62.5 ± 7.7	1.72 ± 0.08
2	3	373	72.2 ± 3.4	1.94 ± 0.09
2	2	416	88.2 ± 3.7	2.50 ± 0.07
2	Daily	435	113.2 ± 6.7	2.07 ± 0.09

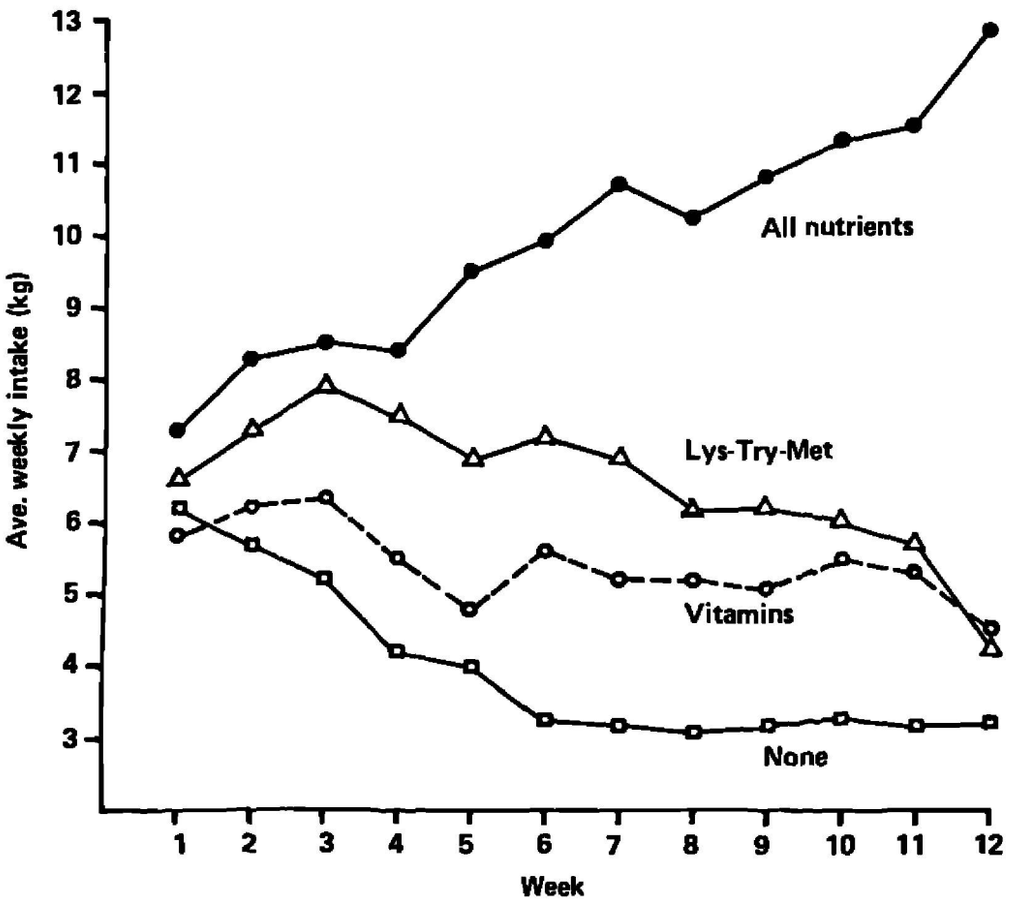

FIG.1. Feed intake of young pigs fed an 89/13 corn/bean diet with various supplements.

TABLE VII. NITROGEN BALANCE OF YOUNG ADULT HUMAN SUBJECTS FED COOKED BEANS

No. of subjects	Nitrogen intake (mg/kg · d)	Nitrogen absorbed (mg/kg · d)	Nitrogen retained (mg/kg · d)
6	115.6 ± 0.9	69.8 ± 2.6	−13.0 ± 1.4
9	127.0 ± 0.73	69.0 ± 4.9	−19.0 ± 6.8

Navarrete, Elías and Bressani (unpublished results).

The effect of protein quality and other nutrients on food intake

One aspect that is not fully recognized in terms of human nutrition, although often observed in animal nutrition, is that protein quality as part of a good balanced diet stimulates food intake. This is shown in Table VI. The addition of 2 grams of powdered milk to a basic diet of corn and beans supplemented with vitamins, minerals and energy daily or at different frequencies stimulated the intake of corn/beans, which in turn induced better weight and higher efficiency of protein utilization [5]. Better protein quality is not the only nutritional factor stimulating food intake, vitamins for example also have a significant influence [6]. Some representative results are shown in Fig.1. In this case 5-week-old piglets were fed a corn/bean diet in an 87/13 proportion by weight. One group of animals in individual pens was fed the diet without vitamins and another group the diet supplemented with a vitamin-B mixture. The intake in kg/week is consistently higher in those animals fed the diet with vitamins; the lack of these nutrients resulted in a decreased intake with time [6].

The same effect on intake is also observed when the supplement consisted of the limiting amino acids of the diet. The intake was high at first while other nutrient reserves in the animal organism were still available, but as these became depleted intake decreased. On the other hand, the complete diet stimulated intake over the 12 weeks of the study.

Bulk and food intake

An additional factor that may be of significance in controlling an adequate food intake and consequently of protein, energy and other nutrients is the bulk of the diet, which may be defined as 'having a full stomach' resulting from high

TABLE VIII. FOOD INTAKE OF YOUNG PIGS (5 WEEKS) FED CORN/ BEAN DIETS

Diet (%)		Ave. food intake (kg)	Ave. weight gain (kg)	Feed efficiency
Corn	Beans			
87	13	118.4	35.0	3.41
70	30	117.4	37.0	3.17
Control		157.7	54.9	2.88

fibre content, high fat or slow digestion rate. An example of the effect of this factor for adult humans is shown in Table VII. These subjects were fed 0.64 g protein/kg·d from beans. The values show that the group did not reach positive nitrogen balance with this intake. In other words, this relatively high level of protein did not provide the amount of methionine needed to induce positive nitrogen retention, and no more beans could be fed since the subjects refused them.

A second example is shown in Table VIII. In this case one group of young pigs was fed ad libitum a diet made of 87 parts corn and 13 parts beans, a second diet consisted of 70 parts corn and 30 parts beans, and a third or control group was fed a balanced diet for animals of that age. The higher intake of food in the control group over the values observed in the other two groups suggests that the animals had the capacity to eat, particularly since the food was available. However, the bulk of the corn/bean diets was such that they were not able to increase their intake. Protein quality in this case did not play a role since the diets were supplemented with the amino acids found limiting in the 87/13 or 70/30 corn/bean diet [6].

Environment and nutrition

It is a well-known fact that the efficiency of the biological utilization of nutrients in foods is also dependent on the environment and especially on good sanitary conditions. It must, however, be recognized that public health intervention has only a limited impact if an adequate diet is not available. On the other hand, it has been possible to show some beneficial effects of nutrient addition on the nutritional and health status of children. Table IX shows that corn fortification with soybean protein resulted in a decrease in mortality rate to three times lower than that observed for groups who did not consume the fortified food.

TABLE IX. INFANT MORTALITY DURING CORN FORTIFICATION SANTA MARIA CAUQUE JUNE 1972 – JANUARY 1976 [7]

Group of fortification	Number of deliveries	Deaths			
		Still births	0–11 months	Total	Rate[a]
0–19	166	6	15	21	127
20–39	23	0	4	4	174
40–100	115	2	3	5	43
Total	304	8	22	30	99

[a] Rate per 1000 deliveries.

TABLE X. WEIGHT GAIN OF YOUNG PIGS FED CORN/BEAN DIETS WITH VARIOUS SUPPLEMENTS, ALONE OR COMBINED

Supplement	Corn/beat diet 87/13 (kg)	Corn/bean diet 70/30 (kg)
None	2.35	10.88
+ Amino acids	14.75	13.63
+ Vitamins	8.50	15.88
+ Minerals	14.63	17.88
+ Calories	6.00	8.63
All nutrients	35.00	37.00
Control	54.88	54.88

TABLE XI. RELATIONSHIP BETWEEN NA TO NB FROM COMMON AND *opaque-2* MAIZE AND MILK

Protein source	NB = a + b (NA)	NA for NB = 0 (g P/kg · d)
Common maize	NB = −85.03 + 0.31 (NA)	1.71
Opaque-2 maize	NB = −71.93 + 0.72 (NA)	0.62
Milk	NB = −40.98 + 0.73 (NA)	0.35

TABLE XII. EFFECT OF REPLACING COMMON CORN WITH *opaque-2* ON A CORN/BEAN DIET [9]

Type of corn in corn/bean diet	Nitrogen balance (mg/kg · d) N intake	N absorbed	N retained
Common	399	247	41
Opaque-2	407	242	115
Common	451	269	90
Opaque-2	498	297	171

TABLE XIII. EFFECT OF BEAN FREQUENCY INTAKE WHEN FED WITH COMMON OR *opaque-2* CORN

	Common corn		*Opaque-2* corn	
Frequency of bean intake	Ave. weight gain (g)	Carcass N (g)	Ave. weight gain (g)	Carcass N (g)
Corn alone	46	2.47	95	4.49
For 12 days	74	3.17	98	4.74
For 20 days	75	3.23	93	4.41
For 28 days	103	4.02	97	5.14

The study also showed a significant difference in the morbidity between children with high and low fortification during the second and third years of life.

These results can be explained on the basis that an improvement in the protein quality of the diet increases the body's response to infections, breaking in this way the vicious circle disease-malnutrition-disease [7].

The need for nutritionally balanced diets

As indicated above, to obtain good nutrition it is necessary to consume a balanced diet. Although this would seem to be obvious, it is often forgotten, particularly in developing countries, where more attention is given to the energy and protein content of diets.

The individual and combined effects of various groups of nutrients added to a daily diet of corn and beans as consumed in Guatemala is shown in Table X. In this case 5-week-old swine were used. The results show significant effects due to minerals, vitamins and amino acids added individually and striking ones when added together. Increased energy density in the diet for a protein content of 9.3% did not result in any benefit in performance. Although it is recognized that swine grow faster than human beings and that many nutrient deficiencies in humans have not been detected, these results show the need to think in terms of all nutrients. Of interest is the effect of poor quality diets on food intake, probably reducing appetite [6].

The information so far presented indicates, therefore, that a number of factors influencing food intake are responsible for malnutrition in many areas of the world. The role of protein quality will now be discussed.

THE ROLE OF PROTEIN QUALITY IN CEREAL GRAINS FOR DIETS

By now the superior quality of *opaque-2* maize over that of common maize is well known. To indicate its practical nutritional significance, however, it is of interest to show its nutritive quality again. Table XI summarizes the regression equations of nitrogen absorbed to nitrogen balance obtained in 4 5 year-old children fed common and *opaque-2* maize and milk. From these regression equations it can be seen that the quality of *opaque-2* maize is similar to that of milk and both are twice as high as that for common maize [8]. For nitrogen equilibrium 1.71 g/kg·d of protein absorbed are needed for common maize and only 0.62 for *opaque-2* maize. As shown in Table XII, the higher quality of *opaque-2* maize is also observed when fed together with beans, a second important staple of the diets of large population groups [9]. Since bean protein induces an improvement in the quality of common maize, this would indicate that if beans and common maize were to be consumed on a daily basis, the practical nutrition

TABLE XIV. AMOUNT OF CORN PROTEIN FOUND EXPERIMENTALLY TO BE NECESSARY FOR NITROGEN EQUILIBRIUM IN CHILDREN AND ADULT SUBJECTS

	Type of corn		
	Opaque-2 corn	Common corn + Lys + Try	Common corn
		Children	
g protein/child · d	16.8	22.0	45.0
g corn/child · d	188	244	500
kg corn/child · a	69	89	182
ha/person · a	0.013	0.017	0.035
		Adults	
g protein/head · d	27.9	–	43.8
g corn/head · d	250	–	547
kg corn/head · a	91		200
ha/person · a	0.018		0.040

On the basis of a yield of 5000 kg/ha.

significance of *opaque-2* maize would be less important. On the other hand, if beans are not consumed on a daily basis, as is the case either because of cost or other reasons, the importance of *opaque-2* corn becomes even more significant. Therefore, the frequency of intake of at least one high-quality food is important. Results showing this are summarized in Table XIII, which demonstrates that as frequency increases, the performance of the experimental animal improves for common corn. However, when *opaque-2* maize is fed, the frequency of bean intake loses significance.

These results demonstrate, therefore, that improving the protein quality of cereal grains consumed daily in relatively large amounts ensures good protein nutrition regardless of whether other supplementary foods are available and consumed by the family or not.

There are other implications in frequency of intake not often appreciated, but one that seems of importance is the adaptation of the individual to daily high and low protein intakes, both in quantity and in quality. Nutritional surveys from which typical diets have been described have introduced much confusion

in the energy-protein problem, despite the fact that they have been useful. These surveys represent average values where everyone surveyed seems to get all foods every day, with a high frequency.

The concept of agricultural productivity

The increased attention given in very recent years to the intensification of food crops and animal productivity by governments, financial institutions and scientists is the result of the analysis of the present and future food situation in the world. It is recognized that the world population is rapidly increasing, particularly in the developing countries. Furthermore, the per capita food production is not keeping pace with the population growth, the increasing purchasing power of people everywhere, particularly in developed countries, is demanding food products of animals fed on grain, and population pressures are diverting arable land to urban and industrial uses. For example, in 25 major rice-consuming areas for 1970 [10], particularly in the most populated, rice provided more than two-thirds of the calories and more than half of the protein. Furthermore, the area of arable land was as low as 0.056 ha/capita. However, expressing the significance of rice in such broad terms as crude calories and total protein is not enough to understand the full meaning of productivity. To meet the challenge of providing sufficient food for people, three major sets of biological processes are being maximized: the efficiency of the plant to utilize energy, carbon dioxide and water to produce desirable products; the more efficient use of soil nutrients and their supply; and biological processes dealing with a more efficient control of disease and pests. These activities together will result in an increase in production, which is now called **productivity.**

'Productivity', however, should not be expressed in terms of increased production per unit area, or production or income per farmer, or number of people fed per farmer. The term should also include the efficiency with which agricultural products, particularly food crops, can contribute to improving nutrition, and in order to do so, productivity should also be viewed as the efficiency with which the nutrients in the food best meet the needs of the populations, particularly of those with greater nutrient requirements. This, in turn, can be translated into a more efficient use of the land and of other imputs in food production. A further attribute to be considered in producitivity is technological efficiency. This component takes into consideration such things as quality of conservation, acceptable characteristics for the consumer and from industry, as well as other desirable functional properties.

One example that shows the effect of better land use through a more efficient utilization of the protein in cereal grains is presented in Table XIV.

For children the protein needed for equilibrium, that is when there is neither gain nor loss, is equivalent to 69, 89 and 187 kg/a of *opaque-2* maize, amino

TABLE XV. AMINO ACID INTAKE FROM CORN WHEN FED IN AMOUNTS TO MEET FAO/WHO PATTERN IN IDEAL PROTEIN

	Amino acids in 0.55 g protein/kg	In corn protein (mg/g)		Daily intake of corn protein to satisfy AA requirement (g/kg)		Amino acids in a daily intake of protein	
		Opaque-2	Common	*Opaque-2*	Common	*Opaque-2* 0.44 g	Common 0.59 g
Isoleucine	9.9	31	37	0.32	0.27	13.6	21.8
Leucine	13.8	81	125	0.17	0.11	35.6	73.7
Lysine	12.1	42	27	0.29	0.45	18.5	15.9
T.S.A.A.[a]	13.2	30	35	0.44	0.38	13.2	51.3
T.A.A.A.[b]	13.8	80	87	0.17	0.16	35.2	51.3
Threonine	7.2	32	36	0.22	0.20	14.1	21.2
Tryptophan	3.6	12	6.1	0.30	0.59	5.3	3.6
Valine	9.9	48	27	0.21	0.21	21.1	28.3

[a] T.S.A.A.: Total sulphur amino acids.
[b] T.A.A.A.: Total aromatic amino acids.

TABLE XVI. AGRICULTURAL PRODUCTIVITY OF CEREAL GRAINS OF IMPROVED NUTRITIONAL VALUE

Parameter	Output/Input	
	Common corn	*Opaque-2* corn
For N inputs in corn production		
Agricultural efficiency (grain)	0.61[a]	0.61[a]
Nutrition efficiency	0.19	0.44
For energy input in corn production		
Agricultural efficiency (grain)	2.82[a]	2.82[a]
Nutritional efficiency	0.87	1.35

[a] Equal yield/ha was assumed.

acid supplemented maize and common maize, respectively. These amounts in terms of protein are lost through faeces and urine since the figures represent the condition at protein equilibrium, and are equivalent to 0.013, 0.017 and 0.035 ha per person per year. For adults the results show the same trend, that is lower land losses due to a more efficient utilization of the nutrients in *opaque-2* maize than those in common corn. This is also true, even if one accepts a 10 15% lower yield from *opaque-2* maize. Therefore, productivity as expressed in production per unit area should also include the efficiency of utilization of the crop produced. Even with the 10–15% lower yield and with a slightly lower technological factor *opaque-2* maize has a higher productivity than common corn. There are other ways to analyse the problem. Table XV shows a different approach. In this case the amount of corn protein needed to meet the essential amino acids in 0.55 g/kg·d of ideal protein was calculated, also for common corn and *opaque-2* maize [11]. This calculation shows that for common corn 0.59 g of protein are needed to meet the tryptophan levels of 3.6. For *opaque-2* maize 0.44 g protein are needed to meet the total sulphur amino acid level of 13.2. With these two figures calculations were made to determine the intake of all other amino acids. The figures are shown in the last two columns for both types of corn. Subtracting from these figures the respective values in the ideal protein and adding up all differences, it is found that *opaque-2* maize gives an excess of 73.1 mg as opposed to a value of 153 mg for common corn, twice as high. This, then, was interpreted

to mean the inefficiency with which the protein in common corn is utilized, since all those amino acids would be completely wasted, having taken energy, space, capital investment and time to accumulate them in the kernel. The situation for children is even more dramatic, since 831 mg of amino acids would be lost from common corn but only 231 mg from *opaque-2* maize. A similar case can be made for rice.

The distinction must be made between physiological hunger, or the need to have a full stomach, and nutritional hunger, i.e. the need for balanced nutrition. This latter implies that a highly nutritious food intake is that utilized by the animal or human organism with a minimum of waste, providing at the same time adequate amounts of the nutrients needed to meet the demands for the efficient physiological functioning of the organism. It is clear that better protein quality is important, not only with respect to the individual consuming such protein, but also in terms of the energy and other activities, including arable land that is used to produce the food crop. It is recognized, however, that total production is the first priority and also that the situation is not as dramatic if one considers that cereal grains are consumed with other protein sources, such as legume grains, which are protein supplements to cereal grain protein. The effectiveness of this supplementary effect, however, depends on the essential amino acid content of the two foods.

It was indicated in the introduction that protein quality is also of agricultural significance. One way of looking at this aspect has already been discussed in terms of land needed for corn and *opaque-2* maize for human feeding. A second way is to calculate the agricultural efficiency of the energy and nitrogen inputs to produce a cereal crop. In this example, corn will again be used. Table XVI gives the basic information [8, 12] as well as the efficiencies. For nitrogen inputs the agricultural efficiency for grain is 0.61 whether for common or *opaque-2* maize. However, the nutritional efficiency of the nitrogen input is 0.44 for *opaque-2* maize and a significantly lower value of 0.19 for common corn. For energy inputs the returns of agricultural efficiency for both types of corn would be 2.82; on the other hand, the nutritional efficiency of the energy input would be 1.35 for *opaque-2* corn and a very low value of 0.87 for common corn.

These calculations indicate that independent of the nutrition problem there are practical advantages to producing basic food grains of the highest protein quality possible.

Nutritional standards for plant breeders

As indicated previously, independently of whether there is or is not an energy or protein problem much can be gained by up-grading the quality of the basic food crops. The question is how much. An attempt to answer this is provided in Fig. 2 [11], which summarizes a very large number of biological studies

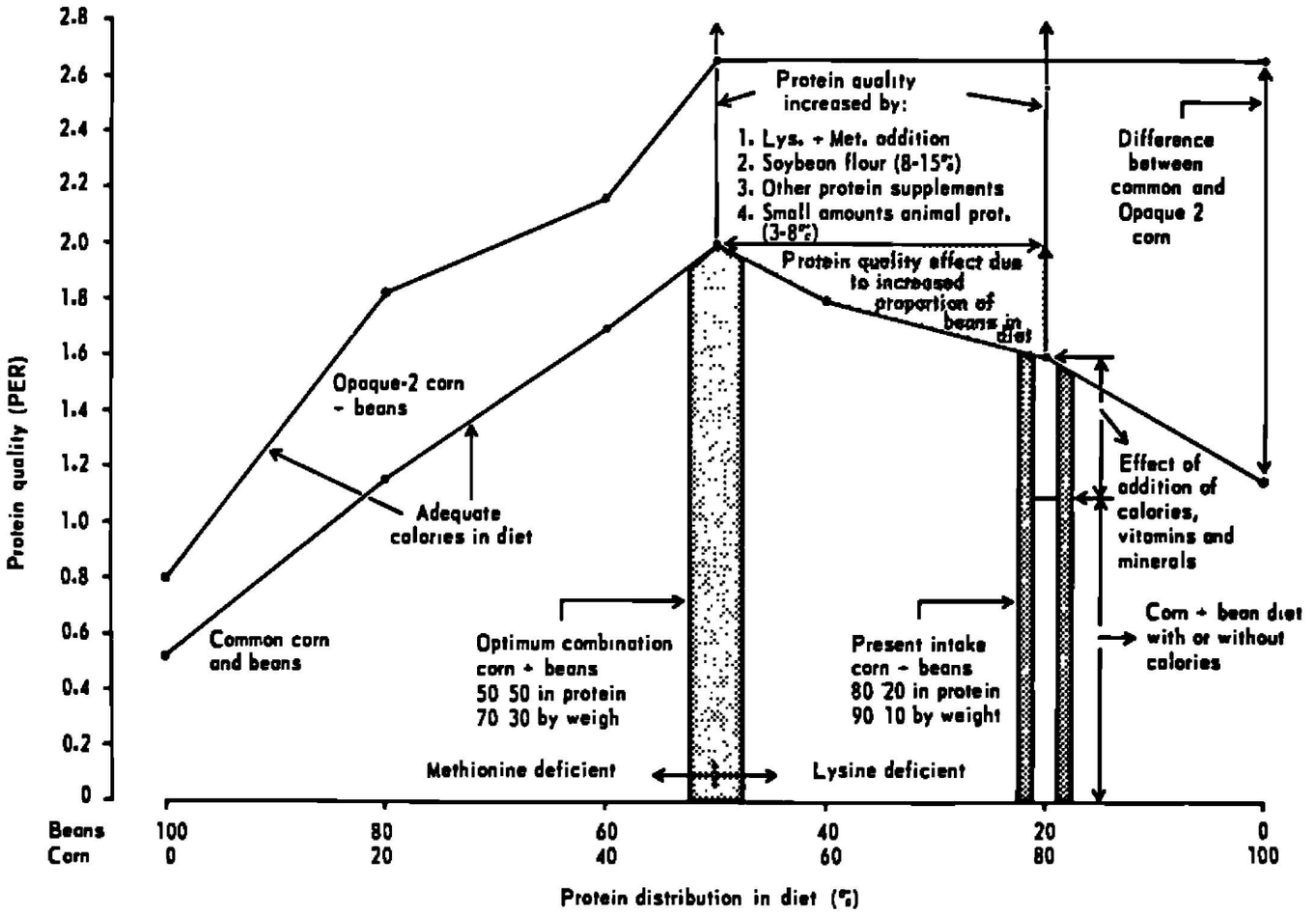

FIG.2. Protein quality of corn/bean mixtures and methods of improvement for optimum efficiency of protein utilization.

using experimental animals; the results have also been confirmed in children. The figure shows the maximum protein quality value of combinations of common corn and beans and of *opaque-2* maize and beans. The value is the same for both situations at a 50/50 protein contribution, except that it is higher for *opaque-2* maize. Furthermore, the protein quality line for this corn does not decrease as its concentration increases, as for common corn. These results were obtained using adequate amounts of calories in the diet. For common corn and beans any combination to the left of the maximum point, i.e. as more beans are present in the diet, is deficient mainly in methionine. To the right of the maximum point, i.e. as more corn is present in the diet, it becomes more and more deficient in lysine. The efficiency of utilization of the best mixture of corn and beans or of the present mixture is improved by the kinds of supplements shown in the figure, but not by additional calories supplied as fat, at least in experimental animals.

The present intake ratio for adults and children in Guatemala, for example, is shown in the bar at the right, with a lower protein quality value, which increases to the maximum by having more beans in the diet. This is shown by the hatched areas between and above the two columns. Now, if the increased intake of corn were to take place, as suggested as a solution to the nutrition problem, and bean

TABLE XVII. PROPOSED NUTRIENT LEVELS IN VARIOUS CEREAL AND LEGUME GRAINS OF COMMON CONSUMPTION IN DEVELOPING COUNTRIES

Basic food	Protein (%)	Lysine (g/16 g N)	Tryptophan (g/16 g N)	Total sulphur amino acids (g/16 g N)
Maize	13 14	3.6 3.8	0.80 – 0.90	3.2 – 3.4
Sorghum	14 15	3.6 3.8	0.80 – 0.90	3.2 – 3.4
Rice	8–10	3.5 3.6	0.80 – 0.90	3.2 – 3.4
Beans[a]	28–30	6.3 – 6.4	1.10 1.20	2.3 – 2.4
Beans[b]	28 30	6.3 6.4	1.10 1.20	3.2 – 3.4
Cowpea[a]	28 30	6.3 6.4	1.10 – 1.20	2.3 2.4
Cowpea[b]	28 30	6.3 6.4	1.10 – 1.20	3.2 – 3.4
Pigeonpea[a]	28 30	6.3 6.4	1.10 1.20	3.2 3.4

[a] When supplement to cereal grains.
[b] When supplement to cassava-based diet.

intake remains the same, it would mean a shift to the right of the present mixture and such a diet would be more deficient in lysine with a decrease in efficiency of utilization.

This, however, does not take place if intake of *opaque-2* corn increases, provided the grain replaces common corn. It should be indicated that the present ratio of 90/10 corn/beans has not changed since at least 20 years ago when there were less people than today with a greater production per capita. This may suggest both that no more of the same two foods can be ingested and that the present ratio represents the optimum caloric intake for the protein ingested.

Very little information is available on the possible nutritional benefits to be derived from a higher protein content in basic food grains. The data available suggest that as protein content increases protein quality decreases; however, the decrease in quality may not be as significant in practice as higher protein content. There are two advantages to a higher protein concentration. One is that higher intakes of protein are possible with less material, which is of importance if the food tends to be bulky. The second is that if the decrease in quality is not large enough, more total protein is utilized from a higher protein food.

The evidence available indicates very clearly that nutritionally improved varieties of cereal grains and food legumes will have a significant impact on the nutritional condition of humans regardless of whether calories or protein are most needed. Furthermore, higher protein quality will be a very valuable asset for future generations in the context of the entire problem of food production, land and people. The difference in opinion between the importance of calories and protein is really a relative one, since both are required and people need food, which should be the carrier of the nutrients needed. The critical point is whether quality protein can be introduced into food crops as known and consumed today, without interfering with other attributes such as yield, appearance and technologically desirable characteristics. To do so, it is important to define and establish the content and technological characteristics together with the yield. These attributes have not been defined or established and in this last section some nutritional standards will be proposed based on the work carried out, indicating that it is essential to establish in the near future the methodology that can provide better values. Essential amino acid patterns have been proposed as a reference [11]. This ideal pattern, however, can be obtained from a single food or from a combination of foods or diet with proteins that complement each other. Which approach should be used? Both have advantages and disadvantages; however, the standard on a per food basis, probably the preferred approach, has the disadvantage of requiring greater efforts to achieve and to maintain other desirable characteristics at the same time. On the other hand, the approach on a diet basis is easier to achieve, with lower risks of interfering with other attributes and it also appears to be more practical.

From a large number of chemical and biological studies, including (a) analytical analysis of the nutrients of interest, (b) amino acid and protein supplementation studies in experimental animals and human subjects of single foods and mixed diets, and (c) feeding experiments of free choice of foods, limiting nutrient levels have been calculated as shown in Table XVII.

As shown, it would be highly desirable to have a higher protein content in both cereal grains and legume foods. Likewise, lysine in cereal grains should, as a first approximation, not be higher than 3.8 g/100 g in cereal grain and about 6.4 g/100 g in legume foods. Tryptophan should be as high as 0.90 g/100 g in cereal grains and 1.20 g/100 g in legume foods. Finally, methionine or total sulphur amino acids should be between 2.4 and 3.4 g/100 g, depending on where it is to be used.

As indicated, the values shown were calculated from a variety of feeding studies using mixed diets. More precise values may be obtained by additional research and biological confirmation in which breeders and biochemists have better contacts. It is hoped that this type of approach to the problem of improving the protein quality of the main basic food crops will stimulate more research in this area and, what is more important, applications of the results obtained.

CONCLUSION

The object of the paper was to show the effect that protein and, more specifically, protein quality has within the context of the malnutrition problem of the world. The evidence presented is truly overwhelming, particularly for protein quality. It is recognized, however, that protein quality by itself, or any nutrient by itself, does not provide a nutritious diet. The latter must carry all nutrients and, therefore, efforts must be made to increase the availability of the basic staples and a diversity in food items to achieve a complete nutritious diet. Within this context the nutritional characteristic that would have a higher impact is protein quality because of its greater interaction with other nutrients, with food availability and patterns of intake of other foods.

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DISCUSSION

J.R. JIMENEZ: What was the percentage of protein in the *opaque-2* corn that you used?

R. BRESSANI: It was 10% on average.

O.E. NELSON: Mr. Bressani, you commented briefly on the assertions of some nutritionists that virtually any diet of vegetable origin providing sufficient entery furnishes adequate protein, not only for maintenance but even for growth. It strikes me that your research using diets of the type actually consumed by some Guatemalans offers clear evidence that protein of better quality in diets of equal energy contents supports better growth of experimental animals and improves N retention in human subjects.

R. BRESSANI: Diet survey data suggest that calorie and protein intakes are about equally low in Guatemala. However, the methods used to obtain such data leave much to be desired and lead to overestimates of nutrient intakes. Total protein intake may be satisfactory even if protein quality is not. In our work with diets no response has been obtained from calorie supplementation, but there is always a significant response to protein quality improvement. If the protein quality of the basic staples is improved the low energy intakes will be corrected, provided, of course, that enough food is available.