HUMAN NUTRITIONAL NEEDS AND CROP BREEDING OBJECTIVES IN THE INDIAN SEMI-ARID TROPICS*

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For many years it has been widely believed that the major nutritional problem facing the world in general, and the lesser developed countries in particular, was a shortage of protein. This almost unquestioned belief in the primary importance of the so-called "protein gap" has led to the development of many research programmes and nutritional schemes whose objectives are an increase of protein quantity and quality in human diets. One such enterprise, the high lysine maize programme initiated in the early 1960s, has served as a model for other cereal breeding programmes throughout the world. Other examples are to be found in the various food fortification programmes initiated in developing countries.

Over the last few years, criticisms have been levelled against the "protein gap" philosophy.[1] As a result of downward revisions in recommended allowances of protein and to a lesser extent in calories by the Food and Agriculture/World Health Organization (FAO/WHO) expert committee over recent years, the estimated deficiencies in protein in actual diets have become much less significant. New evidence from feeding experiments have also cast doubts on the value of protein supplementation of existing diets and lends support to these downward revisions of requirements. This new information has an important bearing on crop breeding and nutrition projects based on the "protein gap" philosophy.

In this paper we discuss the recent evidence on nutritional availabilities and needs within the semi-arid tropical (SAT) region of India[2]. We draw upon data from surveys and feeding experiments to determine the major limiting factors in existing diets. We then proceed to derive the implications of this for crop breeding and nutrition strategies.

THE EXISTING NUTRITIONAL SITUATION

In India data on the composition of diets of people with different levels of income and living in either rural or urban areas are available. The National Institute of Nutrition (NIN, 18) has estimated that the average availability of cereals per caput per day in India is 395 gm. Pulses comprise a further 51 gm., vegetables 52 gm., fruits 44 gm., milk 108 gm., fats and oils 10 gm.,

* Many of the points made in this paper apply equally well to most of the semi-arid tropical regions in other developing countries. For more details, see Ryan, *et al.* (26,27).

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1. See for example Sukhatme (35, 36), Clark (7) and Sen Gupta (31)

2. The SAT region consists of those parts of nine States where rainfall exceeds potential evapotranspiration for a period of from two to seven months and with annual rainfall of between abou 400 and 1400 mm.

flesh foods 12 gm. and sugar and jaggery 46 gm. Based on the average contents of protein, calories and amino-acids in these foods, as contained in the NIN (18) and Gopalan, *et al.* (12), we have estimated that the average Indian consumes 2028 kilo-calories, 52.43 gm. of protein, and 2.17 gm. of lysine per day. A comparison of these figures with recommended allowances in Table I indicates that the overall Indian diet has a 14 per cent deficiency of calories but an adequate amount of protein, lysine and all the other major essential amino-acids. If we use the average daily Indian requirements of 2220 calories and 30 to 36 gm. of protein, as advocated by Sukhatme (35, p.19), or the even lower requirements (1789 calories and 25.9 gm. respectively) calculated by Clark (7) instead of the 2373 calories and 42.70 gm. used in Table I, we obtain a much more optimistic perspective on the adequacy of the *average* Indian diet.

It is recognized that averages do not mean a great deal when examining nutrition data. Low income people, and particularly infants, pre-school children, and pregnant and lactating women, are the most nutritionally vulnerable sections of the population. The NIN (18), through its National Nutrition Monitoring Bureau (NNMB), has recently conducted one of the most comprehensive studies of rural nutrition amongst various income groups. The result of the 1975 surveys for the two lowest income groups in seven States of India are shown in Table I.[3] The NIN consumption data have been converted by us into nutrient consumption by employing the Gopalan, *et al.* (12) nutritive values for Indian foods; derivations are presented in Table I.

What the table clearly shows is that, compared to the recommended allowances for adult males, in none of the five SAT States is there a major protein deficiency in the lowest income group. In Andhra Pradesh there is a marginal (6 per cent) protein deficiency in the lowest income group. In West Bengal and Kerala, both humid tropical States where starchy foods and rice predominate in the diets, there are major protein deficiencies. In no State are there deficiencies in the major essential amino-acids or in iron.[4]

The primary deficiencies emerging from these data are calories, vitamin A, and calcium.[5] The calorie deficiency in the lowest income group ranges from 60 per cent in Kerala to 12 per cent in Karnataka. In the Rs. 1 to 2 per caput per day income group the calorie deficiency ranges from a high of 40 per cent to a low of only one per cent in the same two States. For vi-

3. According to National Institute of Nutrition (18, p. 2) about 74 per cent of the 2672 households studied by the NNMB were in the two lowest income categories, *i.e.*, with daily per caput incomes less than Rs. 2.

4. Although Table I shows a theoretical adequacy of dietary iron intake in all States, it is clear from work at the National Institute of Nutrition that a major part of dietary iron is not absorbed, leading to widespread deficiency symptoms.

5. Belavady (4) points out that copper, zinc, and vitamin B complex deficiencies also commonly occur in the diets of the lower socio-economic groups in India. We were not able to calculate the dietary intakes of these nutrients from these data. The issue of calcium deficiencies is also complex and it is disputed by the National Institute of Nutrition if such dietary deficiencies as shown here mean one can obtain responses from calcium supplements.

TABLE I—NUTRIENT AVAILABILITIES PER CONSUMPTION UNIT PER DAY IN LOW INCOME RURAL HOUSEHOLDS IN INDIA IN 1975*

Nutrient components	Recommended allowances†		States						
	Adult male	Average Indian	Karnataka	Uttar Pradesh	Andhra Pradesh	Maharashtra	Gujarat	West Bengal **	Kerala **
Per caput daily income Re. 1									
Energy (kcal.)	3000	2373	2636	2146	2037	1915	1899	1839	1239
Protein (gm.)	53‡	42.7	74.0	66.3	49.7	56·9	56.8	46.1	32.2
Lysine (gm.)	0.80	1.36	2.705	2.524	1.895	1.942	2.132	1.789	1.273
Tryptophan (gm.) ..	0.25	1.80	0.852	0.743	0.578	0.650	0.653	0.545	0.357
Methionine + Cystine (gm.)	1.10	0.87	2.521	2.286	1.706	1.789	1.949	1.630	1.079
Leucine (gm.)	1.10	1.23	2.231	5.050	4.459	6.459	5.008	3.713	2.204
Isoleucine (gm.)	0.70	0.80	3.511	2.749	2.256	2.457	2.417	2.137	1.336
Vitamin A(ug.)	750	750	303	125	160	242	202	523	67
Calcium (mg.)	500	572	925	323	424	406	508	309	355
Iron (mg.)	9	15.5	46.3	29.5	25.9	32.2	28.7	28.7	16.2
Per caput daily income Rs. 1-2									
Energy	3000	2373	2957	2344	2321	2372	2066	2535	1779
Protein	53‡	42.7	83.7	71.2	56.1	68.8	59·8	67·5	35·6
Lysine	0.80	1.36	3.172	2.736	2.387	2.433	2.292	2.711	1.347
Tryptophan	0.25	0.18	0.931	0.793	0.669	0.791	0.694	0.909	0.412
Methionine + Cystine	1.10	0.87	2.725	2.456	1.962	2.164	2.048	2.270	1.265
Leucine	1.10	1.23	9.185	5.183	4.187	7·397	4.907	5.037	2.857
Isoleucine	0.70	0.80	3.872	2.923	2.593	2.931	2.433	2.987	1.504
Vitamin A	750	750	193	165	160	256	248	527	81
Calcium	500	572	919	377	484	496	577	485	421
Iron	9	15.5	48.2	31.3	26.8	36.8	29.1	36.0	19.3

* *Sources:* National Institute of Nutrition (18) and Gopalan, *et al.* (12). A consumption unit represents the number of adult male equivalent consumers in the family calculated by assigning women and children weights of 0.9 and 0.2 to 0.6 respectively.

† *Sources:* World Health Organization (38, 39), Food and Agriculture Organization (11), National Institute of Nutrition (18), Sen Gupta (31, p. 20) and FAO/WHO (10). The average Indian allowances are based on a (1971) population weighted average of the requirements for the various age groups.

‡ Assumes protein has 70 per cent of the quality of egg protein.

** Not defined as semi-arid tropical States; they are classified as humid tropical.

tamin A the deficiency range in the lowest income group was 91 per cent in Kerala to 30 per cent in West Bengal. In the higher income group the range was much the same. Dietary (but not necessarily nutritional) calcium deficiencies do not seem to exist in Gujarat and Karnataka but range from 38 to 15 per cent in the other five States for the lowest income group, and from 25 to one per cent in the Rs. 1 to 2 per caput per day income category.

The picture for urban areas would seem to show an even greater deficiency of nutrients amongst urban low income groups than in the rural low income groups, judging from the 1965 National Sample Survey data analysed by Ryan, *et al.* (26).

In view of the apparent lack of deficiencies of proteins and amino-acids in the diets of all low income groups in SAT India, the value of crop breeding and nutrition strategies which emphasize protein quantity/quality must be questioned. Other nutrients, far more deficient than proteins and amino-acids in Indian diets which plant breeders might profitably concentrate upon, can more logically and profitably occupy the attention of plant breeders.

EVIDENCE FROM FEEDING TRIALS

It is recognized that while the per caput availability of nutrients may be adequate, distribution within the family may be to the detriment of vulnerable groups such as pre-school children, and pregnant and lactating women. This seems evident from studies by Srikantia (33), Bailur and Chinoy (3), Rao *et al.* (23) and others.

The basic issue is whether these vulnerable groups can benefit from improvements in protein percentages in foodgrains and in protein quality. Bailur and Chinoy found with rats that the addition of lysine to diets similar to those of Indian pre-school children (*i.e.*, calorie deficient) produced no effect on the protein efficiency ratio or on weight gains.[6] In another study, Reddy showed in feeding experiments (24) with six pre-school children that if the child consumes enough wheat to fill the 30 per cent calorie deficiency, the protein and lysine deficiencies are also taken care of. No fortification of improved quality of the diet was necessary. Pant, *et al.* (20) demonstrated that the addition of lysine (L-Lysine monohydrochloride) to wheat-based diets in rats gave significantly greater weight gains than the wheat-based diets without lysine supplementation. However, this was under *ad libitum* feeding. What proportion of this enhanced weight gain was due to the additional food *per se* and what was due to lysine was not specifically examined. They did find however that when feeding was restricted in both the lysine-supplemented and the non-supplemented wheat diets there were *no* significant differences in weight gains. Vitamin and mineral supplements gave significant weight gains under the restricted and *ad libitum* situations. They concluded that, in the presence of vitamin and mineral deficiencies in the diet, (the present situation for the vulnerable groups) the effect of adding lysine to cereal-based diets on growth of rats was negligible. This is supported by Mclaren (13, pp.94-95) who discusses calorie-protein malnutrition and marasmus as follows:

> Marasmus results from grossly restricted intake of *all nutrients and*
> Dietary factors, especially in marasmus, are of second-line order of importance, and in a multi-factorial aetiology poverty, ignorance, bad housing, poor hygiene, and lack of family planning all conspire. Food-consumption data and dietary surveys incriminate energy rather than protein deficit. Increasing the energy intake and not that of protein has produced catch-up growth in undernourished children. Lack of

6. Sukhatme (36) found in various studies that 15 per cent of Indian children had protein ciencies. Of more interest, no children had diets adequate in calories but deficient in protein, there were children with the reverse situation.

nutrient in general with an energy gap rather than a protein gap is the crux of the matter; but how to match the intake of the child with its requirements remains a problem of puzzling complexity." (Emphasis is added.)

These results contrast with the experiments of Singh and Axtell (32) in which rats receiving monograin diets of high lysine sorghum lines from the Ethiopian collection under conditions of adequate vitamins and minerals were compared with rats receiving either normal sorghum, maize and opaque-2 maize. As would be expected under these artificial conditions, the high lysine sorghums gave significantly higher weight gains involving much greater feed-and protein efficiency ratios than did normal sorghum or maize. Of more relevance is the value of high lysine sorghums under dietary conditions existing in the real world.[7]

Alleviation of the predominant deficiency—that of calories—basically requires an increase in food consumption, particularly among the vulnerable groups in the low income categories. Improvement in the quality and quantity of protein in the *existing* diets of the vulnerable groups by fortification and/or new crop varieties will not achieve as much as will an increase in the quantity of their existing diets, which will supply not only much needed calories, but in the process will overcome any protein or amino-acid deficiencies.[8] Grain protein quality improvement by genetic means will not help the vulnerable groups a great deal, as even with significant progress in improving grain protein quality, the amounts eaten are such that the overall dietary position is little improved. Groups now vulnerable will remain vulnerable in spite of grain with increased protein content, as their vulnerability lies primarily in lack of food. McLaren (13) states that more and better protein is likely to be the answer to childhood malnutrition only for populations subsisting largely on starchy roots low in protein. These populations represent only about five per cent of the world's malnourished, and they reside in humid tropical areas like Kerala and West Bengal.

IMPLICATIONS OF NUTRITIONAL STATUS FOR CROP BREEDING STRATEGIES

The inference from the previous discussion is that crop improvement programmes for developing countries with SAT climates should give major emphasis to yield improvement, along with yield stability via insect and disease resistance/tolerance and enhanced characteristics as preferred by consumers. Improved protein and amino-acid contents, whilst desirable in themselves, should not rate a high priority. This is particularly evident when one takes into account the general inverse relationship existing across genotypes between protein percentage and yield per hectare and between protein percentage and

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7. Many other feeding experiments which make the same error could be cited. Payne (19) reviews a number of them. He concludes as long as diets contain at least a 5.4 per cent utilizable protein/energy ratio this should be sufficient to ensure a negligible risk of specific protein deficiency. According to Sukhatme (37), most cereals eaten in India have protein scores greater than this and certainly diet surveys point to values in the total diets much above 5.4 per cent.

8. Added vitamins and minerals may be needed however, and breeders should be encouraged to examine the feasibility of selecting cultivars for those attributes.

the lysine percentage of the protein. This has been shown for sorghum by a number of workers, namely, Collins, Afifarin, Banteyahu, and Campbell and Pickett as reported by Pickett and Oswalt (21); Mohan and Deosthale (14); Schaffert (29); and by Schaffert, *et al.* (30). The same inverse relationship for yield and protein percentage is evident in the world winter wheat collection, Stroike and Johnson (34); Indian wheats, Austin *et al.* (2); and for grain legumes, Adams(1).

Apparently it is extremely difficult to successfully combine the attributes of yield, protein content, and protein quality in one variety. The above inverse relationships, together with experience with the high lysine maize programme at *Centro Internacional de Majoramiento de Maiz Y Trigo* (CIMMYT) do not support a major effort directed at achieving all three attributes.[9] Since in SAT India nutritional needs are primarily for calories, vitamins, and minerals, breeding for yield increases (even at the expense of some protein content if this eventuates) ought to rate first on the priority list. Breeders could also devote more attention to the possibility of selecting foodgrain cultivars with superior contents of digestible carbohydrates, calcium, iron, copper, zinc and vitamin A and vitamin B complex. All have been found deficient in Indian diets—yet to our knowledge no plant breeder is purposively screening germplasm for these attributes. Instead, in the nutritional phase of breeding programmes there is almost exclusive concentration on protein content and quality.[10]

Belavady (4) suggests that amongst improved Indian sorghum cultivars there is a wide range in contents of tannins (which affect iron absorption and protein utilization), carotene (vitamin A), iron, copper, calcium and zinc.[11] Unfortunately, as is generally also the case with protein and amino-acid contents, there are large environmental effects across locations and years. The ranking of cultivars with respect to nutrient contents changes substantially, depending on when and where they are grown. This is illustrated by the fact that crossing of the high lysine Ethiopian sorghums both at ICRISAT and in the All India Co-ordinated Sorghum Improvement Programme has not yet produced viable lines which yield well and retain the protein content and quality of the parents.

9. The high lysine maize programme commenced in 1963 with the discovery of the mutant "Opaque-2" gene by E. T. Mertz and his co-workers at Purdue University. The original mutant had a floury soft endosperm which weighed less than that of normal maize and hence yields were 10 to 15 per cent less. The soft endosperm was also more susceptible to Fusarum, ear rots and insects. Pinstrup-Anderson (22) found that it was also discounted by more than 10 per cent on the market due to its appearance and inferior cooking quality. Even in 1977 research workers have not been able completely to overcome the disadvantages of the "opaque-2" gene. *Centro Internacional de Majoramiento de Maiz Y Trigo* (CIMMYT) (3, p. 52) however believes commercial promotion of opaque-2 maize is rapidly approaching and may be imminent. This remains to be seen. The point is that 14 years is too long to consider in the present context of developing countries, where breeding strategies should recognize the difficulties of evolving such material and instead concentrate on yields.

10. Of course most breeders do stress yield as well as protein.

11. Analyses we have done on the NNNB data show that for major sorghum eating States like Maharashtra, Madhya Pradesh, Karnataka and Gujarat, sorghum contributes upto 50 per cent of the calories and iron, 18 per cent of the calcium, and 20 per cent of the vitamin A in the diets of the lowest income group. Hence the scope for overcoming defi. iencies in these nutrients by screening cultivars in sorghum breeding programmes appears promising.

Various authors have reported that a large range (from 57 to 77 per cent) in starch content exists in sorghum cultivars.[12] At the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) we have found a correlation of —0.68 (significant at one per cent) between protein percentage and starch percentage amongst 23 sorghum cultivars selected to give a representative cross-section. This evidence suggests that when cultivars are selected for high protein content, it is likely that at the same time one is excluding those cultivars with a higher starch content. In view of the predominance of calorie deficiencies in Indian diets, such a selection criteria requires re-evaluation.

To determine the likely effects of a successful "yield-oriented" plant breeding strategy on nutritional well-being in India we have taken the example of sorghum. We have used the data from the National Sample Survey conducted by the Cabinet Secretariat of the Government of India (5) for 1964-65. Using the low income group we calculated that with a yield increase of about 10 per cent the price of sorghum in India could fall by about 25 per cent to world price levels, assuming price elasticity of demand of—0.3 and that other things remain equal.[13] For each income class, based on the quantity of sorghum consumed, the direct impact of this price fall on sorghum consumption is estimated using—0.3 as the price elasticiy. Then the effect of the price reduction on real income is calculated and, using income-consumption curves from the National Sample Survey of the Cabinet Secretariat (5), the additional consumption of all foods which would occur as a result of this additional income is calculated. The results indicate that, on an all-India basis, the nutritional effect of a 10 per cent sorghum yield increase would be to increase the availability of protein, calories and lysine in the *average* Indian diet by about one per cent. The contribution of sorghum to this directly was calculated to be from 40 to 50 per cent of the increase in the rural areas and 50 to 70 per cent of it in the urban areas. The remainder was generated via the additional consumption of other foods that the reduction in the price of sorghum would allow. The major sorghum eating States according to the surveys conducted by the NIN recently (17) are Madhya Pradesh, Maharashtra and Karnataka. The lowest income rural families in these States consumed 455, 262 and 263 gm. of edible sorghum per consumption unit per day, while the 1964-65 all-India average was only 26 gm. for the urban areas and 62 gm. for the rural areas according to the Cabinet Secretariat (5). The effect of successful yield-increasing, relative price-reducing technology in sorghum on the real income of these consumers will thus be much greater than for all-India. The estimated effect of a 10 per cent yield increase is shown in Table II for low income rural people in the

12. See Miller and Burns (15) and Rooney and Clark (25).

13. Historical data from the Food and Agriculture Organization (11) and the Government of India, Directorate of Economics and Statistics (8) suggest that Indian wholesale prices for sorghum have historically been about 25 per cent above world prices. World prices should therefore present a floor below which Indian prices would not fall. We assume that the relative prices of other food-grains remain the same in this exercise, as does the area sown to sorghum.

three major States. The availability of nutrients to them could be improved by almost 10 per cent.[14] This is a significant improvement which again emphasizes the potential nutritional and welfare impact of successful yield-oriented crop breeding programmes.[15] Elsewhere Ryan and Asokan (28) have demonstrated that the new HYVs of wheat introduced into India did in fact produce such a significant nutritional improvement.

TABLE II—IMPACT OF 10 PER CENT YIELD INCREASES AND RELATIVE PRICE FALL IN SORGHUM ON CONSUMPTION AND NUTRITION IN HIGH SORGHUM CONSUMING RURAL LOW INCOME FAMILIES IN INDIA*

State	Increase in nutrient consumption per consumption unit per day†		
	Protein (gm.)	Calories (kcal.)	Lysine (gm.)
Madhya Pradesh	9.77	301	0.27
Maharashtra	7.19	222	0.22
Karnataka	4 83	187	0.15

* Data are from the National Institute of Nutrition (17) for rural families with a monthly income averaging Rs. 210 in 1974, combined with income by consumption data from the Cabinet Secretariat (5). Family size averaged some 6.7 persons in the surveys.

† See Footnote to Table I for definition of a consumption unit.

CONCLUSION

The overriding nutritional deficiencies in the diets of the lowest income groups in SAT India are calories, calcium, copper, iron, zinc, and vitamin A and vitamin B complex. Protein and amino-acids do not appear to be limiting factors. As Sukhatme (35, p. 9) puts it:

> "It follows that the policies and plans to combat protein malnutrition which take as a first reference point for attack the existing inequalities in protein consumption must clearly give way to policies and plans to combat inequalities in the quantity of diet. And since the quantity of diet is primarily determined by the level of income these policies and programmes must aim at eliminating inequalities in the income itself, at least to enable the poor to have minimum income to afford the cereal/pulse-based diet adequate to meet their energy needs."

The implication of the preceding analysis for crop breeding strategies in SAT India is that, to the extent that the attainment of increased yield potentials in improved cultivars is made more difficult by trying to include increased protein content and quality attributes, priority should be given to yield and yield stability. Indeed, unless protein improvements are very easy to achieve in crop breeding, it is doubtful if they are worth pursuing at all, given the implicit trade-offs involved. Screening of advanced elite breeding

14. It should be noted that for these same income groups their existing diets contain more than the recommended allowances of proteins and amino-acids.

15. The highly significant correlations of +0.87 between sorghum yield per acre and protein yield per acre and +0.92 between sorghum yield per acre and lysine yield per acre shown by Schaffert (30, p. 15) amongst genotypes, reinforces the thesis being advanced here.

lines for protein content and quality should be all that is required, and this only to ensure they do not fall below existing levels. Early generation screening for protein is of doubtful value.

The evidence suggests that, if it is indeed beneficial and feasible to include nutritional attributes in crop breeding objectives in SAT India, then it is vitamins, minerals, and digestible carbohydrates—and not protein—which should be included. More research is required to determine the extent to which these characteristics are heritable before one would wish to advocate programmes which screen and select for these.

Breeding strategies which emphasize yield and yield stability offer the best prospects for improvng nutritional well-being of the least nutritionally and economically affluent groups in SAT India. Increased yields and production of foodgrains has a direct impact on prices and real incomes of the least affluent groups, who spend a large amount of their incomes on foodgrains. Increased real income will enable them to purchase additional foodgrains and hence improve their nutrition. If yield potentials of cereals, pulses, oilseeds and other crops could all be substantially increased, nutritional improvements will follow as these all have complementary nutritional compositions. It is not necessary that any one of the grains have a "balanced content" of all nutrients, which is the underlying premise of cryptic quality breeding programmes. People eat more than one food item each day. Making available additional quantities of all foods is the appropriate nutritional strategy. Nutrition education can help ensure that the correct mix is consumed. It is unwise and unreasonable to expect any one grain to provide a balanced diet.

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