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ICRISAT Research and Human Nutrition*

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This paper highlights the nutritional aspects and implications of research done by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). The research activities of ICRISAT that have to do with nutrition can be grouped in two categories:

1. Those directed toward understanding and documentation of the nutritional status of people, factors that affect nutrition status, and the desirable components of technologies for addressing nutrition problems.
2. Those designed to affect the determinants of human nutrition.

The first category is largely reflected in the work of social scientists and biochemists, who highlight the nutritional problems and analyze the determinants of nutrition to help define and plan research policies. Biochemists analyze the nutrient components of various crops and cultivars, thereby assisting plant breeders in the selection and incorporation of valuable crop characteristics and in understanding the nutritional quality of the newly developed material.

The activities in the second category include research by agrobiological and physical scientists that is directed toward development of crop-centered and resource-centered technologies for semiarid tropical areas--technologies that will ultimately influence the quantity, quality, and composition of food production, income, and employment and finally of consumption. These activities have to do with commodity priorities, commodity characteristics, technology characteristics and production-systems research as suggested by Pinstrup-Andersen.[1] For want of space, however, the present discussion will be confined to the first two aspects.

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[1] Per Pinstrup-Andersen, Incorporating Nutritional Goals into the Design of International Agricultural Research (Washington, D.C.: International Food Policy Research Institute, 1983).

RESEARCH TO UNDERSTAND NUTRITIONAL ISSUES AND PROBLEMS

An understanding of human nutritional status and the factors affecting it is an essential step toward a sharpening of the nutritional focus of prospective technologies. This involves research activities in the following two categories:

1. Research directed toward understanding the current nutritional status of people in semiarid tropical areas;
2. Research directed toward understanding the food quality of ICRISAT mandate crops.

On Current Nutritional Status

The ICRISAT research directed toward understanding the current nutritional status of rural populations in semiarid tropical areas has been largely confined to India.[2] Its objectives are to arrive at an understanding of the factors that influence the nutritional status of people and to derive useful inferences to help agrobiological scientists to attune their research strategies to nutritional issues. In some instances nutrition per se is the goal of research, while in others nutrition emerges as a component of the complex of issues studied. These studies have been conducted largely by economists in collaboration with nutritionists, biochemists, physiologists, and medical scientists.

Determinants of Individual Diet and Nutritional Status of People in Semiarid Tropical Villages in India. A detailed collaborative study was conducted by ICRISAT, the National Institute of Nutrition, and the Home Science College of Andhra Pradesh Agricultural University between 1976 and 1978 to determine the nutritional and health status of residents of semiarid tropical villages in Southern India. The study covered 1,200 people from a panel of 240 households in six villages of three agroclimatic zones throughout four seasons. The principal nutrient deficiencies found were energy, calcium, and vitamins A, B

[2] Most of the attempts to understand the nutritional problems of Africa have been made by reviewing past investigations; see D. W. Norman et al., Farm and Village Production Systems in the Semi-Arid Tropics of West Africa: An Interpretative Review of Research, Research Bulletin No. 4 (Patancheru, Andhra Pradesh, India: ICRISAT, 1981), and Barbara Harris, The Marketing of Foodgrains in the Sudano-Sahelian States: An Interpretative Review of the Literature, Economics Program Progress Report 31 (Patancheru, Andhra Pradesh, India: ICRISAT, 1982). The village-level studies being conducted by ICRISAT in West Africa will also throw some light on the nutritional problems of the people; see P. J. Matlon, Profile of Farm Units in Two Villages of Central Upper Volta, West Africa Economics Program Progress Report 1 (Kamboinse, Upper Volta: ICRISAT, 1980), and John McIntire, Reconnaissance Socioeconomic Surveys in North and West Upper Volta, West Africa Economics Program Progress Report 3 (Kamboinse, Upper Volta: ICRISAT, 1982).

complex, and C. Protein was generally not limiting. Villages whose diets consisted largely of sorghum and pearl millet had better vitamin and mineral intake than the largely rice-consuming villages. The nutritional status was found to be determined primarily by agroclimatic and socioeconomic characteristics of villages rather than by the level of net household income. There was little seasonal variation in intakes of nutrients other than vitamin B complex, the consumption of which increased during the season of surplus foodgrains. In view of the importance of vitamin and mineral deficiencies found in the study villages, programs to increase the production of vegetables, dairy products, and fruits that contain significant quantities of these nutrients would seem appropriate. The role of common property resources (CPRs), such as village forests, pastures, ponds, and rivulets, from which people gather a variety of food and fodder freely, thus assumes greater significance. The calorie deficit should be overcome largely by increasing the availability of foodgrains, especially cereals. Crop-breeding programs can make a significant contribution to this effort by focusing on increasing and stabilizing crop yield.[3]

A further analysis of the data highlighted some aspects of intra-household allocation of nutrients. In the surplus season nutrients are allocated among children in households in the village-level study with some concern about distribution and not just about productivity--that is, parental inequality aversion. But in the lean season when food is scarcer there is much less concern about equality and the expected health outcome of boys and older children is favored over that of girls and younger children. Furthermore, in the lean season households that hold land favor older children less than those who do not. And households with more educated heads favor boys less in the surplus season, but more in the lean season.[4]

Nutritional Imbalances Induced by the Green Revolution. The spread of high-yielding varieties of wheat at the cost of acreage--and production--of pulses, a principal source of protein, became a matter of serious concern during the early 1970s. Its possible implications in the appearance of nutritional imbalances was examined by means of secondary data from important wheat-growing states in India. The study revealed that significant improvement in wheat production--caused by a plant-breeding strategy to increase yields--overcompensated for the possible decline in nutritional well-being of the people from the decline of pulse production in India. One reason that wheat could displace pulses to such a large extent, however, was that increases in wheat yields occurred at a time when yields of pulses were stagnant. This indicates the need for improving yields of pulses to

[3] J. G. Ryan et al., The Determinants of Individual Diets and Nutritional Status in Six Villages of South India, Research Bulletin No. 7 (Patancheru, Andhra Pradesh, India: ICRISAT, 1984).

[4] J. R. Behrman, Intra-household Allocation of Nutrients in Rural India: Are Boys Favoured? Do Parents Exhibit Inequality Aversion?, Economics Program Progress Report 67 (Patancheru, Andhra Pradesh, India: ICRISAT, 1984).

prevent their prices from reaching a level that would take them out of reach of the nutritionally vulnerable and economically poor. The need for a breeding strategy for increasing the yield of pulses also became apparent.[5]

Human Nutrition and Crop-Breeding Objectives. Review of dietary surveys and related literature on the semiarid tropics showed that diets were deficient in calories, vitamin A, vitamin B complex, and some minerals, although deficiencies in proteins and amino acids were not as great as they were believed to be in the 1960s.[6] This suggests that higher priority should be given in the ICRISAT crop-improvement programs to breeding for increased yields and therefore more calories than to breeding for greater protein content and higher protein quality. Screening for high protein content may be confined to the elite progenies in a breeding program to ensure that the lines released have satisfactory nutrient profiles after other priorities have been met.[7] A review of this research by the governing board of ICRISAT was partly responsible for changes in breeding priorities in favor of higher and more stable yields, particularly in sorghum.

Nutrition and Traditional Farming Systems. Comprehensive village-level studies in semiarid tropical areas in India and in parts of West Africa have revealed several ways in which good nutrition and food management can be achieved through traditional farming systems. Mixed cropping or intercropping, involving a combination of crops with different food values, maturity periods, capacity to withstand hazards, and salvage possibilities, represents one of the most important practices that characterize traditional farming systems.[8] Intercropping and crop diversification can minimize crop fluctuations and the number of total crop failures, thereby helping to stabilize income

[5] J. G. Ryan and Muthiah Asokan, "The Effects of the Green Revolution in Wheat on the Production of Pulses and Nutrients in India," Indian Journal of Agricultural Economics 32 (July-September, 1977): 8-15.

[6] J. G. Ryan et al., Human Nutritional Needs and Crop Breeding Objectives in the Semi-Arid Tropics, Economics Program Occasional Paper 4 (Patancheru, Andhra Pradesh, India: ICRISAT, 1974).

[7] Ibid.; and J. G. Ryan et al., Human Nutritional Needs and Crop Breeding Objectives in the Semi-Arid Tropics: A Further Note, Economics Program Occasional Paper 8 (Patancheru, Andhra Pradesh, India: ICRISAT, 1975).

[8] N. S. Jodha, "Intercropping in Traditional Farming Systems," Journal of Development Studies 16 (July 1980): 427-442; P. D. Bidinger and Bhavani Nag, "The Role of Pigeonpeas in Village Diets in the Semi-Arid Tropics of South India," in Proceedings of the International Workshop on Pigeonpeas, vol. 1 (Patancheru, Andhra Pradesh, India: ICRISAT, 1981), pp. 257-264; McIntire, Reconnaissance Socioeconomic Surveys.

and food supply.[9] The traditional integration of crops, livestock, grass, bushes, and trees into a total farming system underscores the importance of self-provisioning and food security.[10]

Drought-Induced Instability of Food Intakes and Nutritional Levels. A substantial decline in the consumption of food, particularly "protective" foods such as milk, vegetables, fruit, and meat, and in expenditures by farmers for food was observed in drought-affected areas of India. Curtailment of consumption, partly because of reduced supplies and partly because of the need to reduce current commitments, suggested the need for technological and institutional means of increasing and stabilizing crop production to protect people's nutritional status.[11] The quest for short-term food security also influenced the decisionmaking of farmers. Shortages in their own food supplies and lack of purchasing power encouraged such practices as agreements to working as attached labor, insistence on wages in kind, seasonal migration, tenancy, and the linking of various factor markets and product markets in villages.[12]

9 R. P. Singh and T. S. Walker, Determinants and Implications of Crop Failure in the Semi-Arid Tropics of India, Economics Program Progress Report 40 (Patancheru, Andhra Pradesh, India: ICRISAT, 1983); T.S. Walker et al., Dimensions of Farm Level Diversification in Semi-Arid Tropics of Rural South India, Economics Program Progress Report 51 (Patancheru, Andhra Pradesh, India: ICRISAT, 1983).

10 Helga Vierich, "Anthropology in the Context of ICRISAT's Objectives in West Africa: Progress to Date and Plans for 1983," report prepared for ICRISAT in-house review, 1983; N. S. Jodha, "Market Forces and Erosion of Common Property Resources," paper presented at the International Workshop on Agricultural Markets in the Semi-Arid Tropics, ICRISAT, Patancheru, Andhra Pradesh, India, October 24-28, 1983.

11 N. S. Jodha, "Famine and Famine Policies: Some Empirical Evidence," Economic and Political Weekly, October 1975, pp. 1609-1623; N. S. Jodha, "Effectiveness of Farmers' Adjustment to Risk," Economic and Political Weekly, June 1978, pp. A.38-A.48; N. S. Jodha and A. C. Mascarenhas, "Adjustment to Climatic Variability in Self-Provisioning Societies: Some Evidence from India and Tanzania," ICRISAT Conference Paper No. 129, presented at the meeting of the Scientific Committee on Problems of Environment (SCOPE), Canadian Climate Centre, Toronto, Canada, September 27-October 7, 1981.

12 H. P. Binswanger et al., "Common Features and Contrasts in Labor Relations in the Semi-Arid Tropics of India," in Contractual Arrangements, Employment, and Wages in Rural Labor Markets in Asia, ed. H. P. Binswanger and M. R. Rosenzweig (New Haven: Yale University Press, 1984), pp. 143-168; N. S. Jodha, "Agricultural Tenancy in Semi-Arid Tropical India," in Contractual Arrangements, Employment, and Wages in Rural Labor Markets in Asia, ed. H. P. Binswanger and M. R. Rosenzweig (New Haven: Yale University Press, 1984), pp. 96-113.

Nutrition as a Determinant of Labor Wages and Participation Rate. ICRISAT research has indicated the adverse effects of tractorization and of herbicide-based weed management on employment.[13] Women, who are often at risk nutritionally and who are the principal source of labor for weeding, are the ones who suffer the most from the introduction of herbicides.[14]

Analysis of data on village labor markets--participation rates, wage rates, composition of wages, the provision of meals along with wages, cash, and payment in kind--indicated that a better nutritional status conferred a significant positive effect on the daily wages of men but not on those of women.[15] The effect on participation was the opposite, however. Women who were better nourished participated more actively in the daily market for casual agricultural labor, while the nutritional status of men was not significantly associated with their participation in the labor market. This explains in part why men are given priority in the allotment of food supplies in low-income households in rural areas. It also explains to some extent the tendency for a diversion of food away from nutritionally vulnerable members to the male adults in a family under the nutrition intervention programs for vulnerable groups.[16]

An econometric analysis of agricultural wages and farm productivity further demonstrated the importance of health in the short-term in influencing the marginal productivity of labor. For every percentage point increase in the standardized weight-for-height of a worker, ceteris paribus, his daily agricultural wage rate as well as the marginal productivity of his labor on the family farm increase by Rs 0.03 (the daily agricultural wage rate at the sample mean is Rs.2.45). This is a rather large effect, which suggests that investments in nutrition to increase the weight-for-height of individuals would have high returns in agriculture. So would other policy interventions that allow more weight-for-height to be 'produced' from given nutritional intakes by improving the general health environment and reducing the incidence of diseases.[17]

[13] H. P. Binswanger, The Economics of Tractors in South Asia: An Analytical Review, ADC-ICRISAT Monograph (Patancheru, Andhra Pradesh, India: ICRISAT, 1977).

[14] H. P. Binswanger and S. V. R. Shetty, Economic Aspects of Weed Control in Semi-Arid Tropical Areas in India, Economics Program Occasional Paper 13 (Patancheru, Andhra Pradesh, India: ICRISAT, 1977).

[15] J. G. Ryan, Wage Functions for Daily Labor Market Participants in Rural South India, Economics Program Progress Report 38 (Patancheru, Andhra Pradesh, India: ICRISAT, 1982).

[16] Ibid.

[17] A. B. Deolalikar, Are There Pecuniary Returns to Health in Agricultural Work? An Econometric Analysis of Agricultural Wages and Farm Productivity in Rural South India, Economics Program Progress Report 66 (Patancheru, India: ICRISAT, 1984).

Elasticities of Demand for Protein and Calories. Income and price elasticities of demand for protein and calories were derived through an analysis of data on consumption collected in the National Sample Survey in India. Income and price elasticities of demand for both calories and protein are highest among the poorest consumers, particularly in rural areas. Sorghum and millet are significant components of the diets of very poor people, indicating that a breakthrough in the technology of production of these crops will bring about substantial nutritional gains for the poor.[18]

Analysis of Consumer Preference for Sorghum and Pearl Millet. Assuming that market prices reflect the preferences of consumers, relating these to characteristics of preferred foods revealed that protein content, cooking quality, and absence of glumes and molds in grain are important determinants of consumer preference for certain varieties of sorghum and millet.[19] The influence of nutrient content was confirmed by consumer panel studies.[20] These findings offer useful information for crop breeders in their efforts to make new cultivars acceptable to consumers. On the basis of the estimation coefficient for the relevant quality characteristics, a selection index can be derived to predict the preference of consumers for any new variety.

Common Property Resources and Human Nutrition. The initial results of a study of rural CPRs--resources used by the whole community without any exclusive right of individual ownership--revealed their significant contribution to human nutrition, particularly of the rural poor. The latter gathered fruit, leaves, flowers, honey, game, fish, wild cereals and legumes, and off-season vegetable crops from various CPRs, such as forests, pastures, wastelands, ponds, and rivulets, in the villages. The nutrients that are often unavailable from field crops

[18] K. N. Murty and Matthias von Oppen, "Nutrient Distribution and Consumer Preference in India, with Policy Implications," paper presented at the International Workshop on Agricultural Markets in Semi-Arid Tropics, ICRISAT, Patancheru, Andhra Pradesh, India, October 24-28, 1983.

[19] Matthias von Oppen and P. P. Rao, "A Market Derived Selection Index for Consumer Preference of Evident and Cryptic Quality Characteristics of Sorghum," proceedings of the International Symposium on Sorghum Grain Quality, ICRISAT, Patancheru, Andhra Pradesh, India, 1982; Matthias von Oppen and Ramamurthi Jambunathan, "Consumer Preference for Cryptic and Evident Quality Characteristics of Sorghum and Millet," paper presented at the Diamond Jubilee Scientific Session of the National Institute of Nutrition, Hyderabad, India, October 23-27, 1978.

[20] P. P. Rao and Matthias von Oppen, Village Consumer Preference for Sorghum Varieties and Its Relationship to Sorghum Preference Index, Economics Program Progress Report 50 (Patancheru, Andhra Pradesh, India: ICRISAT, 1983).

and that are too costly or of too low a priority to be bought were gathered free from CPRs. In village households in semiarid tropical regions, these products comprised 9 percent of the diets of small farmers but only 4 percent of the diets of large farmers.[21]

Nutritional Considerations in the Allocation of Research Resources. In response to specific requests from ICRISAT policymakers, some exercises using different criteria were done to evaluate the present priority of nutrition in the allocation of resources. The relative contributions of mandate crops to total nutrient production in various regions was one criterion that indicated the need for a shift in allocation of research resources in favor of Sub-Saharan Africa.[22] Details of this work will form part of the section on commodity priorities.

These studies are summarized in Table 9.1.

Nutritional Quality Dimensions of Mandate Crops

The nutritional profiles of mandate crops are determined through chemical and biochemical analyses by the department of grain quality and biochemistry. This work covers the nutritional composition of grain, the effects of processing methods and techniques on nutritional composition, and antinutritional factors and their removal in processing. In the past these separate aspects have not been given equal emphasis.

Nutrient Profile of Mandate Crops. The main emphasis in the past has been on the analysis of mandate crops for their chemical composition, particularly proteins, carbohydrates, amino acids, minerals, and trace elements. Of late, processing methods have received fairly high priority. The department of grain quality and biochemistry analyzes thousands of samples of mandate crops from germ plasm accessions as well as from breeding material. The following are among its findings.

Improvement of Protein Quality Through Breeding. Genetic variability for protein content has been explored for improvement of

[21] N. S. Jodha, "Market Forces and Erosion of Common Property Resources," paper presented at the International Workshop on Agricultural Markets in the Semi-Arid Tropics, ICRISAT, Patancheru, Andhra Pradesh, India, October 24-28, 1983.

[22] J. G. Ryan, "Agriculture and Research in the Semi-Arid Tropics," paper prepared by the Economics Program for the Quinquennial Review of ICRISAT, Patancheru, Andhra Pradesh, India, 1978; Matthias von Oppen and J. G. Ryan, Determining Regional Research Resource Allocation Priorities at an International Agricultural Research Center, ICRISAT Journal Article No. 293 (Patancheru, Andhra Pradesh, India: ICRISAT, 1984).

Table 9.1--Summary of ICRISAT research directed toward understanding of issues and problems related to human nutrition

Subject or Study	Principal Findings and Recommendations	Potential Users of Results	Relevant Area of Research Policy
1. Determinants of diets and nutrition status of people in semiarid tropical villages (Ryan et al. 1983, Behrman 1984)	Diets are deficient in energy, calcium, and vitamins A, B complex, and C, rather than in protein. Villages that consume sorghum and millet have better vitamin and mineral intake than those that are dependent on rice. Village-specific agroclimatic and socioeconomic factors have a greater bearing on intake of nutrients than does annual net income. Nutrient allocation to children is governed by concern for equity during the surplus season and productivity during the lean season.	Nutrition policymakers, research policymakers	Commodity characteristics, production systems
2. Nutritional imbalances induced by the green revolution (Ryan and Ashokan, 1977)	Improvement in wheat yields overcompensated for possible decline in nutrition on account of decline in yields from low-yielding pulse crops.	Nutrition policymakers, research policymakers, breeders	Commodity priorities, commodity characteristics, production systems
3. Human nutrition and crop-breeding objectives (Ryan et al. 1974, 1975)	Yield improvement should be given priority over protein-quality improvement.	Research policymakers, plant breeders	Commodity characteristics

Table 9.1 (Continued)

Subject or Study	Principal Findings and Recommendations	Potential Users of Results	Relevant Area of Research Policy
4. Nutrition and traditional farming systems (Jodha 1980, Singh et al. 1983, Walker et al. 1983, Bidinger and Nag 1981, McIntire 1983, Vierich, 1983)	Better food mix, self-provisioning, and food stability through reduced crop failure can be achieved by means of intercropping and crop diversification.	Research policymakers, nutrition policymakers	Production systems, technology characteristics
5. Drought and food intake instability (Jodha 1975, Jodha and Mascarenhas 1983, Binswanger et al. 1984)	Decline in food intake as a first step in adjustment to drought; other decisions with long-term implications for nutrition concern attached labor, tenancy, factor-market linkages, and migration.	Development and relief policymakers and planners	Production systems, commodity characteristics
6. Common property resources and human nutrition (Jodha 1983)	Poor derive significant quantities of free goods with nutritional value from common property resources.	Planners and policymakers, research policymakers	Production systems, commodity characteristics
7. Nutrition as a determinant of labor wages (Ryan 1982, Deolalikar 1984)	Better nutritional status has significant positive effect on wages of adult males, which has intrahousehold implications for food distribution. Short-term health factor (proxied by weight-for-height) positively influences wage rate as well as marginal productivity of farmers' labor.	Nutrition policymakers, planners	Production systems

Table 9.1 (Continued)

Subject or Study	Principal Findings and Recommendations	Potential Users of Results	Relevant Area of Research Policy
8. Elasticities of demand for nutrients derived from elasticity of demand for commodities Murty and von Oppen 1983)	Price and income elasticity of demand are highest among the rural poor. Sorghum and pearl millet contribute significantly to their intake of calories and protein.	Research policy-makers, breeders	Commodity priorities, production systems
9. Consumer preference for certain qualities in sorghum and millet (von Oppen et al. 1982, Rao et al. 1983)	Protein content, cooking quality, and cleanliness are important determinants of consumer preference, as revealed by market price indexes and consumer panels.	Plant breeders	Commodity characteristics
10. Nutrition and allocation of research resources (Ryan 1978, von Oppen et al. 1983)	Priorities in allocation of regional research resources need to be changed.	Research policy-makers	Commodity priorities

protein quality through breeding.[23] The range in the protein content of the samples analyzed was 4.4-21.1 percent in sorghum, 5.8-20.9 percent in pearl millet, 10.6-31.1 percent in chick-pea (whole seed), and 13.2-26.5 percent in pigeon pea. Protein content was highest in wild relatives of chick-pea and pigeon pea, ranging from 25.6 percent to 31.7 percent and from 28.3 percent to 30.5 percent, respectively. These pulses could be sources for development of high-protein lines.[24]

The results of a study using the two high-protein, high-lysine sorghums as parents suggested that the high-lysine gene may not be stable.[25] It may vary in different environments and with different agronomic practices. This has led to a lessening of emphasis on breeding for high-protein sorghum. Similarly, the instability of chick-pea protein under varying field conditions in different years has meant less progress in the protein-improvement program.[26]

The analysis of a diverse range of germ plasm of pearl millet revealed the possibility of selecting for greater content of protein and basic amino acids--of which lysine is the most important--by monitoring the levels of lysine and protein, respectively, without detriment to grain yield or grain weight. Grain yield was not found to be significantly correlated in pearl millet to either protein content or basic amino acids.[27]

Antinutritional Factors. The levels of various antinutritional factors, principally in chick-pea and pigeon pea, have been studied. Large differences have been found among protease inhibitors in

[23] Ramamurthi Jambunathan et al., "Grain Quality of Sorghum, Pearl Millet, Pigeon Pea and Chickpea," paper presented at the Workshop on Interfaces Between Agriculture, Nutrition, and Food Science, ICRISAT, Patancheru, Andhra Pradesh, India, November 10-12, 1981.

[24] Umaid Singh et al., "Seed Protein Fractions and Amino Acid Composition of Some Wild Species of Pigeonpea," Journal of Food Science and Technology 18 (May-June 1981): 83-85; L. J. Reddy et al., "Seed Protein Studies on Cajanus, Atylosia spp. and Some Hybrid Derivatives," paper presented at the International Symposium on Seed Protein Improvement in Cereal and Grain Legumes, sponsored by International Atomic Energy Agency and the Food and Agriculture Organization of the United Nations, Munich, West Germany, 1978.

[25] K. W. Riley, "Inheritance of Lysine Content and Environmental Responses of High and Normal Lysine Lines of Sorghum bicolor (L) Moench in Semi-Arid Tropics of India" (Ph.D. dissertation, University of Manitoba, Canada, 1980).

[26] Umaid Singh et al., "The Protein Content of Chickpea (Cicer arietinum L.) Grown at Different Locations," Qualitas Plantarum - Plant Foods for Human Nutrition 32 (No. 2, 1983): 179-184.

[27] K. A. Kumar et al., "Relationship Between Nutritional Quality Characteristics and Grain Yield in Pearl Millet," Crop Science 23 (March-April 1983): 232-235.

cultivated and wild species of pigeon peas.[28] Considerable variation seems to exist among the chick-pea cultivars with respect to trypsin and chymotrypsin inhibitors and amylase inhibitors.[29]

Polyphenolic compounds, commonly referred to as tannins, act as nutritional inhibitors in coarse grains. They have been reported to reduce the bioavailability of protein and other nutrients, but at the same time polyphenols, particularly in sorghum, have been shown to contribute some degree of resistance to or tolerance of depredation by birds, preharvest germination, and withering.[30] Polyphenols in chick-pea and pigeon pea inhibit the activity of digestive enzymes.[31] Considerable differences were found in the levels of these inhibitors in different cultivars of these pulses. The level of most of these nutrition inhibitors is low, and they are found principally in seed coats. They are reduced or destroyed in processing and cooking.

Effects on Breeding Programs. While useful information about the chemical composition of grains and antinutritional factors present in them is available to breeders, its use is very much restricted because of the variability and instability of some of the characteristics according to the environment and the agronomic background of the material. Protein improvement and, to some extent, work on food quality are therefore confined to the criterion that the newly developed material, while giving larger, more stable yields, should not prove inferior to existing cultivars in protein and food quality--essential condition for the adoption of new cultivars. Chemical analysis also helps in cautioning the breeders about the possible toxicity of the wild relatives of cultivars used for crossing.

Nutritional Quality and Food-Processing Methods. Because the final availability of nutrients is affected not only by the nutrient content of the grain but also by the method of its processing before consump-

[28] Umaid Singh and Ramamurthi Jambunathan, "Protease Inhibitors and in Vitro Protein Digestibility of Pigeonpea [Cajanus cajan (L.) Mill sp.] and Its Wild Relatives," Journal of Food Science and Technology 18 (November-December 1981): 246-247.

[29] Umaid Singh and Ramamurthi Jambunathan, "Studies on Desi and Kabuli Chickpea (Cicer arietinum L.) Cultivars: Levels of Protease Inhibitors, Levels of Polyphenolic Compounds, and in Vitro Protein Digestibility," Journal of Food Science 46 (September-October 1981): 1364-1367; Umaid Singh et al., "Studies on Desi and Kabuli Chickpea (Cicer arietinum L.) Cultivars: The Levels of Amylase Inhibitors, Levels of Oligo Saccharides, and in Vitro Starch Digestibility," Journal of Food Science 47 (March-April 1982): 510-512.

[30] J. H. Hulse et al., Sorghum and the Millets: Their Composition and Nutritive Value (New York: Academic Press, 1980).

[31] Umaid Singh, "The Inhibition of Digestive Enzymes by Polyphenols of Chickpea (Cicer arietinum L.) and Pigeonpea (Cajanus cajan L.)," Nutrition Reports International 29 (March 1984): 745-753.

tion, food processing is an important determinant of nutrition. Furthermore, the preference of consumers for a product or its quality is guided by its taste and its suitability to preferred processing practices. Food quality, consumer preference, and food technology are therefore integral parts of ICRISAT research in nutrition. At ICRISAT, emphasis on food quality has recently increased, and special attention is being given to food forms and food-processing techniques, qualities preferred by consumers, and food-processing technology.

The effect of the processing method--soaking, milling, cooking, and so on--on the final availability of nutrients and on the reduction of antinutritional factors is being studied. In addition information is being collected on traditional food forms and household processing practices in various semiarid tropical areas. Most research on household processing practices has been focused on sorghum.[32] International sorghum food quality trials were carried out in collaboration with various scientists in Africa and in Latin America. Grain samples from 25 cultivars were evaluated for food quality across an array of foods to learn the possibilities of breeding sorghum with properties that would permit its use for almost all sorghum foods. Correspondence and field evaluation visits by various scientists in Asia, Africa, and Latin America have revealed that most sorghum produced for human consumption is consumed in eight basic forms. Various sorghum cultivars, including roti, have been evaluated in these forms.[33] As mentioned earlier, the work on consumer quality preferences through both market-determined indexes and consumer panels has been done by the economics group.

Promotion of Nutritional Awareness. An important activity of ICRISAT is promotion of awareness of nutrition problems and of possible solutions. Through periodic seminars and workshops it encourages interaction among workers in the field of nutrition, including scientists, policymakers, and field workers in various parts of the world. The biochemistry group takes an important part in such activities. Nutrition and food quality have been integral parts of the themes--in some instances the sole themes--of international seminars conducted periodically by ICRISAT. Two important ones were the International Symposium on Sorghum Grain Quality, sponsored jointly by USAID Title XII Collaborative Research Support Program on Sorghum and Pearl Millet (INTSORMIL), ICRISAT, and the Indian Council of Agricultural Research (ICAR) during 1981, and the Workshop on Interfaces between Agriculture, Nutrition, and Food Science, sponsored jointly by ICRISAT, the

[32] Vaidhyanathan Subramanian and Ramamurthi Jambunathan, "Traditional Methods of Processing of Sorghum (Sorghum bicolor) and Pearl Millet (Pennisetum americanum) Grains in India," Reports of the International Association of Cereal Chemistry 10 (June 1980): 115-118.

[33] D. S. Murty et al., Sorghum Roti: Genotypic and Environmental Variations for Roti Quality Parameters, Proceedings of the International Symposium on Sorghum Grain Quality held at ICRISAT, Patancheru, Andhra Pradesh, India, October 28-31, 1981.

National Institute of Nutrition, Hyderabad, and the United Nations University, Tokyo, during 1981. Such meetings are valuable, not only for exchanging the results of past work, but also as opportunities for collective thinking on the future direction of work relating to nutritional issues. Some of the research findings about the nutritional profiles of mandate crops are summarized in Table 9.2.

RESEARCH DIRECTED TOWARD INFLUENCING NUTRITION

Besides research for the purpose of understanding nutrition problems and related issues discussed in the preceding section, several ICRISAT research activities are designed to influence the nutritional position of its clients. This is done through the development of technologies to increase and stabilize the production and availability of food in semiarid tropical areas. Two processes through which ICRISAT attempts to influence nutrition status are the establishment of commodity priorities or research priorities and the specification of desired changes in commodity characteristics.

Commodity Priorities

Commodity priorities were established by ICRISAT as a part of its research mandate. Accordingly, sorghum, pearl millet, chick-pea, and pigeon pea--staple foods of most people in semiarid tropical areas--were included in its crop-improvement program from the beginning. Groundnut was added later as the fifth mandate crop of ICRISAT. The effectiveness of research on these crops in increasing agricultural production in semiarid tropical areas is revealed by their predominance in these areas. The share of semiarid tropical countries in the total area given to these crops and in total world production of them, respectively, is as follows: sorghum, more than 80 percent and 55 percent; millets, including pearl millet, more than 50 percent and 39 percent; chick-pea, more than 90 percent and 90 percent; pigeon pea, more than 90 percent and 96 percent; groundnut, 77 percent and 65 percent.[34] The share of semiarid tropical countries in world production of these crops is less than their share of the area planted in them because their yields are lower. Their average yields range from about 500 kilograms per hectare for millet to 840 kilograms per hectare for sorghum.[35] Furthermore, yields are highly unstable, principally because of the variability of rainfall and the periodically high incidence of diseases, pests, and insects. Most of the producers are poor; their annual per capita income is less than U.S. $100. Those who rely on sorghum and millet as their staple cereals consume up to 700 grams a day per capita.[36] This description applies to 48 of

[34] Ryan, "Agriculture and Research in the Semi-Arid Tropics."

[35] Ibid.

[36] J. G. Ryan and Matthias von Oppen, "Global Production and Demand for Sorghum and Millet to the Year 2000," paper prepared as a background document for the CGIAR Impact Study, FAO, Rome, 1983.

Table 9.2--Summary of ICRISAT research directed toward understanding the nutritional quality of mandate crops

Subject	Principal Findings
Protein quality	1. High-lysine gene in sorghum is too unstable in varying environments to be helpful in breeding high-protein sorghum (Riley 1980).
	2. Protein content of cultivated chick-pea fluctuates according to field conditions, obstructing work to improve the protein quality (Singh et al. 1983).
	3. Wild species of pigeon pea, the protein content of which is higher, are a potential source for developing high protein lines (Reddy et al.1979).
	4. Yield, grain weight, and protein content of pearl millet are not significantly correlated, indicating the possibility of breeding simultaneously for higher calorie content and higher quality protein (Kumar et al. 1983).
Antinutritional factors	1. Greater trypsin and chymotrypsin activity was observed in wild factors species of pigeon peas. Clear-cut difference in chymotrypsin inhibitors was observed between wild and cultivated species of pigeon pea (Singh et al. 1981).
	2. Chick-pea and pigeon pea contained high level of polyphenolic components, which affected activities of digestive enzymes adversely and had implications for assimilation of nutrients (Singh 1983).
	3. Variation in tannin content was much higher than the variation in other constituents of 18 sorghum genotypes studied (Subramanian 1983).
Food quality	1. Cooking quality of early pigeon pea appeared to be better than that of peas requiring medium and long maturity periods (Singh et al. 1983).
	2. Sorghum roti: significant effects for crop season, year, and genotype-year interaction for grain, dough, and roti quality parameters. Effect of nutrition, fertility level on roti quality was insignificant (Murty et al. 1981).

the 49 semiarid tropical countries that could be described as developing countries.

In keeping with its research mandate, ICRISAT has decided upon its research priorities and the allocation of its resources. Table 9.3 summarizes the pattern of allocation of resources during the period 1980-82. The crop-improvement programs received about 70 percent of the funds, while about 20 percent was allocated to research on farming systems and about 10 percent to economics. Among the crop-improvement programs, that for sorghum received the largest allocation in direct cost and man-years of scientists. Table 9.3 reveals further that the cereals--sorghum and pearl millet together, the staple foods in semiarid tropical areas--received around half the total resources devoted to crop improvement or a third of ICRISAT's research funds. A comparison of the distribution of ICRISAT's resources to mandate crops with the respective importance of these crops as determined by the area given to them and the value of their production in the semiarid tropical world reveals certain imbalances. According to a more detailed analysis by Ryan, pulses are allotted a proportionately larger share of ICRISAT research resources than cereals.[37] If the area devoted to crops rather than the value of production is considered, this imbalance becomes sharper. To a certain extent, however, the effect of this imbalance is reduced once it is realized that national research programs, while devoting considerable resources to sorghum and millet, have usually neglected pulses. It may also be noted that the area sown with pulses and the value of their production are underreported in several countries. An important but subsidiary component of traditional intercropping systems, they are often not fully reported in crop statistics.

Expressed in its aggregate form and unrelated to regional differences in the importance of these crops, the foregoing picture of resource allocation does not tell much about its underlying logic in relation to the nutritional problems of people in the semiarid tropical areas. Increased and stabilized food production, larger incomes, and fuller employment will surely help the poor and inadequately fed people in the semiarid tropical areas. The semiarid tropical countries are not homogenous in the distribution of factors that affect nutrition, however. They differ in per capita income and its growth; in demographic pressures and trends; in current standards of food consumption; in levels, stability, and trends of crop production; in the importance of crops to which research by ICRISAT is devoted; and in the mix of production and consumption. The allocation of the research resources of ICRISAT needs therefore to be evaluated with reference to these variables in the several zones. Such an exercise has been attempted by von Oppen and Ryan.[38] They divided the 49 semiarid tropical countries, which are spread over five continents, into seven groups: India, Eastern Africa, West Africa, Southern Africa, the Near East, Other Asia, and North, Central, and South America. Through the use of data on the aforementioned variables and the

[37] Ryan, "Agriculture and Research in the Semi-Arid Tropics."

[38] von Oppen and Ryan, "Determining Regional Research Allocation Priorities."

Table 9.3--Allocation of resources to various research programs at ICRISAT, 1980-82[a]

Research Programs	Share of the Programs in Resources Allocated: All Research Programs			Share of the Programs in Resources Allocated: Crop-Improvement Programs			Share of Crops in Semi-Arid Tropical Total of 5 Crops[c]	
	Direct Cost	Man-Years of Scientists: Principal	Man-Years of Scientists: Others[b]	Direct Cost	Man-Years of Scientists: Principal	Man-Years of Scientists: Others[b]	Area	Production Value
	(percent)							
Sorghum	19.9	19.5	18.1	28.5	27.7	24.7	39.2	35.4
Pearl millet[d]	15.4	15.8	16.0	22.2	25.3	23.9	30.8	15.4
Chick-pea and Pigeon pea	21.7	19.0	22.9	31.2	28.2	32.6	13.8	18.3
Groundnut	12.6	11.8	13.3	18.1	18.8	18.8	16.2	30.9
Farming systems	19.7	21.0	23.9	...	...	...	...	...
Economics	10.7	12.9	6.1	...	...	...	...	...

[a] Prepared from budget documents. Only direct cost of programs considered.

[b] Includes support staff working in each program.

[c] Area and production value (from Food and Agriculture Organization data) indicate average of 1974-78 in semiarid tropical countries.

[d] Also includes other millets in semiarid tropical countries other than India.

development of a weighting system involving considerations of efficiency and equity, they developed several priority indexes for these regions. Some of the indexes placed greater emphasis on considerations of equity--that is, helping first those who suffer more because of lesser production, consumption, poverty, demographic pressure, and agricultural stagnation--others gave more emphasis to considerations of efficiency. Actual allocation of resources to different crops in different regions was compared with these priority indexes. Resource allocation suggested by one index broadly matched the actual pattern of allocation of research resources to crops and regions by ICRISAT.

This index showed an implicit preference for considerations of efficiency--on the assumption that the effectiveness of research will be greater if the regional contribution of the crop is greater--weighted by ad hoc equity criteria based on such factors as population and food status. ICRISAT plant breeders tend to support this view.

According to the study, in the case of sorghum this index more closely reflects the actual allocation of resources by ICRISAT expressed in principal-scientist equivalents, although in actual terms West Africa is given slightly higher priority and North, Central, and South America slightly lower priorities than those assigned by the index. In the case of pearl millet, actual allocation of resources is almost exactly congruent with the index. For pigeon pea the analysis shows the predominance of efficiency criteria in the allocation of research resources. Since pigeon pea is predominantly an Indian crop, India accounting for about 95 percent of the area devoted to it and of its production in semiarid tropical regions, efficiency criteria favor this pattern of allocation. On the basis of equity concerns, however, regions such as Southern Africa, Eastern Africa, and Southeast Asia seem good candidates for allocation of additional resources to research on pigeon peas. Similarly, on an equity basis there appears to be an overinvestment in chick-pea research in India and the Near East at present, whereas on efficiency grounds there is not. It would seem that there is some case for allotting additional resources to chick-pea research in other semiarid tropical Asian countries, Southern Africa, and the Americas at the cost of India. A similar picture emerges with regard to groundnut. Only equity criteria suggest that there is an overinvestment in groundnut research in India; the use of efficiency criteria presents a picture of congruence between actual allocation of resources and priority indexes.

An important point to be added is that allocation of resources to India by ICRISAT is not directed to India alone. Certain technologies and methodologies that emanate from the ICRISAT Center in India have spillover effects for other regions. This is revealed by prolonged work and visits to other regions by scientists based in India, the transfer of methodologies developed at ICRISAT headquarters to other outreach stations through training, and the distribution of seed material to all regions. Using all these considerations, Swindale developed a more realistic weighting system and found that the actual allocation of resources by ICRISAT to different geographical zones matched quite well with the pattern of resource allocation revealed by their weighting scheme.[39]

[39] L. D. Swindale, "Centers Week Presentation," internal document, ICRISAT, Patancheru, Andhra Pradesh, India, 1983.

Commodity Characteristics

One way to understand the assignment of priorities to specific crop characteristics is to examine the objectives of research projects. An analysis of the objectives of ICRISAT research projects is presented in Table 9.4, which shows the distribution of all research projects that involve mandate crops undertaken during the period 1975-82 according to their main objectives. These projects are grouped into four categories, which may involve some degree of overlapping. Projects in farming-systems research, even when they involve the mandate crops, are not included. Finally, a significant limitation of Table 9.4 is that it deals with the number of projects, irrespective of their size.

Table 9.4--Distribution of ICRISAT research projects among various crops, by principal objectives, 1975-82[a]

Research Objective	Crop				
	Sorghum	Pearl Millet	Chick-pea	Pigeon Pea	Groundnut
			(percent)		
Resistance to yield reducers					
Physiological constraints	21	13	10	8	17
Disease, insects, and pests[b]	49	38	24	36	58
Yield increase per se	5	15	18	8	4
Grain quality improvement					
Nutritional quality	9	10	9	8	-
Consumer preference	5	5	3	2	-
Miscellaneous					
Cross-location, adaptation, etc.	11	19	42	38	21
Total	100	100	100	100	100
(Number)	(38)	(40)	(45)	(51)	(42)

a Based on documents prepared for ICRISAT In-House Review 1981.
b Includes research projects on striga weed also.

An important finding is that through its research ICRISAT attempts to improve nutrition more by increasing the availability of food than by improving its nutritional quality, particularly the quantity and quality of the protein in its mandate crops. Accordingly, nutrition improvement, primarily improvement of protein quality, constitutes the principal objective of only 8-10 percent of the research projects on various mandate crops. This proportion declines further when the projects undertaken before 1979 are excluded. During that period, increasing the protein content and improving its quality were important considerations, particularly in the case of sorghum. The gradual change took place following the increased emphasis on the need for breeding for high yields rather than for high protein content and the realization by breeders of the instability of the protein-promoting gene in different environments and with different agronomic practices.[40] In all mandate crops other than pearl millet, protein improvement has a low priority; in pearl millet it is still emphasized because there is no significant trade-off between research for yield improvement and that for protein improvement.[41] In all crops the important consideration is that protein levels in newly developed materials should not be lower than those in the existing cultivars.

Of late, emphasis has slowly shifted simultaneously to development of the qualities preferred by consumers in grains because it is these qualities, rather than nutritional quality, that determine the acceptance of new material by farmers. The proportion of projects with such objectives, however, hardly exceeds 5 percent of total research projects on any of the crops.

Another fact revealed in Table 9.4 is that development of resistance to biotic and abiotic hazards constitutes a primary goal of a large proportion of the crop-improvement research projects of ICRISAT. Building resistance to diseases and insect pests on the one hand and to physical constraints such as drought, low fertility, salinity, and waterlogging on the other is attempted. The effect of some of the principal yield reducers is revealed by the following broad estimates made by ICRISAT scientists through surveys and field assessments.[42] In the case of pearl millet, downy mildew and ergot diseases cause losses in India of about U.S. $20 million a year, estimated in 1982 prices. Wilt and sterility mosaic in pigeon pea cause annual losses of about $38 million and $66 million, respectively, in India and Africa together. Leaf spot and rust in rainy-season groundnut reduce the yields by half, causing a loss of about $53.3 million a year. Grain molds that substantially reduce the grain price of sorghum cause a loss of about $45 million in India. Annual losses to chick-pea and pigeon pea growers in India caused by the pod borer (*Heliothis armigera*) are estimated at $300 million. Other diseases such as

[40] Riley, "Inheritance of Lysine Content."

[41] Kumar et al., "Nutritional Quality Characters and Grain Yield in Pearl Millet."

[42] ICRISAT, *Challenge and Response, 1972-82* (Patancheru, Andhra Pradesh, India: ICRISAT, 1982).