FCND DISCUSSION PAPER NO. 1

AGRICULTURAL TECHNOLOGY AND FOOD POLICY TO COMBAT IRON DEFICIENCY IN DEVELOPING COUNTRIES

Howarth E. Bouis

Food Consumption and Nutrition Division

International Food Policy Research Institute
1200 Seventeenth Street, N.W.
Washington, D.C. 20036-3006 U.S.A.

August 1994

ABSTRACT

Breeding for food-staple plant varieties that load high amounts of iron and zinc in their seeds holds great promise for making a significant, low-cost, and sustainable contribution to reducing iron and zinc deficiencies in humans in developing countries. This strategy also may well have important spinoff effects for increasing farm productivity in developing countries in an environmentally-beneficial way.

Understanding how household incomes, food prices, and culturally-based preference patterns interact to drive food consumption and nutrient intake patterns can provide crucial background information for designing effective nutrition intervention programs.

Research in both of these areas is being pursued under a five-year project organized by the International Food Policy Research Institute and implemented by the Consultative Group on International Agricultural Research, with funding from the Office of Health and Nutrition of the United States Agency for International Development.

CONTENTS

FOREWORD

This paper presents findings from a project titled "Food Policy and Agricultural Technology to Improve Diet Quality and Nutrition," organized by the International Food Policy Research Institute (IFPRI), implemented by the Consultative Group on International Agricultural Research (CGIAR) and other collaborating organizations, and funded by the Office of Health and Nutrition of the United States Agency for International Development (USAID). IFPRI, one of 18 international research organizations that comprise the CGIAR, undertakes research, primarily from an economics perspective, to assist policymakers in developing countries to increase food production and improve food consumption and nutrition among the poor. The main focus of research at most Centers in the CGIAR, however, is development of improved crop varieties, which increase the food supply and so lower food prices, and raise farm profits and rural employment.

The primary objective of the project is to explore cost-effective alternatives within the CGIAR for increasing micronutrient intakes. There are two broad strategies that the CGIAR can pursue in the area of nutritional improvement. The first broad strategy involves analysis, by social scientists and nutritionists, through the use of household surveys, of the interaction of agricultural technologies generated by the Centers, household resource allocation, and health, nutrition, and other policies implemented by national governments. Through a better understanding of this process, programs and policies may be better designed that enhance beneficial and mitigate harmful nutrition outcomes.

The second broad strategy is to enhance the micronutrient content of edible portions of crops through plant breeding. Plant breeding, which in this context may be viewed as a form of fortification, has tremendous potential for improving micronutrient intakes. This strategy is discussed in the paper, which summarizes one aspect of the discussion and papers presented at an initial organizational workshop for the project held in Annapolis, Maryland, U.S.A., January 10-12, 1994. In particular, the paper draws heavily on a keynote paper entitled "Breeding for Staple-Food Crops With High Micronutrient Density: Long-Term Sustainable Agricultural Solutions to Hidden Hunger in Developing Countries," authored by Robin Graham and Ross Welch. Robin Graham is a Reader in Plant Science at the Waite Agricultural Research Institute, University of Adelaide, Glen Osmond, South Australia. Ross Welch is Lead Scientist and Plant Physiologist, U.S. Plant, Soil, and Nutrition Laboratory (PSNL), United States Department of Agriculture, Agricultural Research Service, Ithaca, New York.

Under the project, initial screening for germplasm variability will commence soon for five staple food crops at three Centers: for rice at the International Rice Research Institute (IRRI) in the Philippines; for wheat and maize at the International Center for Maize and Wheat Improvement (CIMMYT) in Mexico; and for beans and cassava at the International Center for Tropical Agriculture (CIAT) in Colombia. Complementary activities will be undertaken at Waite and the PSNL under the direction of Robin Graham and Ross Welch, respectively.

For further information about the project and copies of the three keynote papers presented at the organizational workshop, please contact Howarth Bouis at IFPRI, 1200 Seventeenth St., N.W., Washington, D.C. 20036; telephone (202-862-5641); fax (202-467-4439); e-mail (h.bouis@cgnet.com). The remaining two keynote papers were delivered by Doris H. Calloway, Professor Emerita, Department of Nutritional Sciences, University of California at Berkeley, "Human Nutrition: Food and Micronutrient Relationships," and Jere R. Behrman, William R. Kenan, Jr. Professor of Economics, University of Pennsylvania, "Household Behavior and Micronutrients: What We Know and What We Don't Know."

AGRICULTURAL TECHNOLOGY AND FOOD POLICY TO COMBAT IRON DEFICIENCY IN DEVELOPING COUNTRIES*

Howarth E. Bouis

1. INTRODUCTION

Food-based strategies hold the promise for treating the underlying causes of mineral deficiencies. However, successful implementation of food-based strategies requires a thorough understanding of the very complex processes involved in the movement of minerals from soils to plants, through marketing systems, and ultimately to utilization for better human nutrition. This paper will argue that a specific food-based approach—plant breeding—not only holds great promise for making a significant, low-cost, and sustainable contribution to reducing iron and other mineral deficiencies in humans, it also may well have important spinoff effects for increasing farm productivity in developing countries in an environmentally-beneficial way.

Understanding the underlying causes of and cost-effective solutions to iron and other mineral deficiencies in human diets in developing countries is a frustratingly complex and inherently interdisciplinary exercise. Minerals are taken up from various types of soils with varying degrees of success through the roots of innumerable types of plants. Depending on a number of factors that are not well understood, these minerals are translocated to varying degrees from the plant roots to various edible portions of the plants.

* Paper prepared for presentation at a workshop entitled "Food-Based Approaches for the Elimination of Hidden Hunger," sponsored by the Department of Human Nutrition of the Wageningen Agricultural University and the Program Against Micronutrient Malnutrition, held in Arnhem, Netherlands, June 12-24, 1994; revised July 1994.

These edible parts of the plants and the minerals contained in them (1) may be directly consumed by members of farm households or their livestock, but (2) most enter some form of marketing system directly as plant products or "indirectly processed" as livestock products. The marketing system may be thought of as a sorting process, which at various points in time provides *potentially* high quality diets for some households, but dictates low quality diets for others, depending on such key factors as household incomes, seasonal food prices, nutritional knowledge, and cultural beliefs and preferences.

A second sorting process goes on inside the household as specific foods may be allocated, for example, according to the age, gender, and/or earning power of particular household members. Finally, the actual nutritional value of the foods consumed (provided by the iron and other minerals contained in them) depends on a host of crucial factors, again that are not well understood, such as the particular combination of nutrients eaten at any given meal (nutrient interactions in the gut and/or the presence of inhibiting and promoting compounds), how the food is processed, stored, and cooked, iron status of the consumer, her morbidity, parasite levels, and physiological status (pregnancy/lactation).

Supplementation, and to a lesser extent, fortification, as strategies to combat iron deficiency, have the advantage that they are interventions at the end, or toward the end of this sequence of linkages. Even though the scientific roadblocks associated with implementation of these two strategies have proven troublesome (for example, manufacturing a pill whose ingredients will provide sufficient bioavailable iron), successful interventions require accurate understanding "only" of human nutrition and/or a narrow spectrum of food marketing and consumption behavior (for example, identifying an appropriate food for fortification).[1] An important drawback to these strategies is that they treat the symptoms rather than the underlying causes of the problem and so involve recurrent costs.[2]

A strategy of breeding plants that load high amounts of necessary minerals into seeds has the potential for substantially reducing recurrent costs. However, this strategy will work only if farmers are willing to adopt such varieties. Therefore, these varieties must either out-yield present varieties or use fewer inputs. As discussed below, prospects are good that both outcomes may occur.

The basic reasons for these agronomic advantages may be stated in a simple way (for details, see Graham and Welch 1994). Plant nutrition may suffer from mineral deficiencies in a number of ways (for example, zinc and manganese play key roles in preventing root disease in wheat). These "deficiencies" are caused not by the physical absence of iron and other minerals in the soil, but by the fact that the iron and other minerals are bound chemically to other elements that make them "unavailable" to plants. Such soil "deficiencies" are widespread in developing countries.

Certain plant genotypes, however, are more efficient than others in the uptake of iron and other minerals from soils (for example, their roots exude substances that chemically "unbind" minerals in the soil, resulting in their becoming available to plants). Plant breeding may select for such "efficiency" characteristics, including the characteristic of translocating

---

[1] Although, once these "scientific" problems have been solved, there are inevitably the organizational problems of program implementation.

[2] Often, the benefit-cost ratios for these recurrent costs are quite high (for example, see Levin et al. 1993). Therefore, it is important to continue these interventions until such time as the underlying causes of iron and other mineral deficiencies can be addressed.

high amounts of iron and other minerals to the plant seeds. When replanted in "deficient" soils, such mineral-dense seeds have been shown to be more vigorous and disease-resistant, which, in turn, leads to higher plant yields, even though fewer chemical inputs and less irrigation are required.

The paper is organized as follows. First, food consumption patterns of poor households in developing countries are discussed at some length in the following section. There is a broad consensus that poor quality diets are the primary cause of micronutrient deficiencies. However, to date little analysis has been undertaken to understand how low incomes and high food prices constrain food consumption choices to produce this pernicious situation. Programs and policies to raise the incomes of the poor and to lower food prices may be powerful tools with which to improve dietary quality. An analysis of consumption patterns for a sample of Philippine households will demonstrate how the optimal mix of interventions can vary widely by nutrient.

The analysis in this section will also show that intakes of food staples in the aggregate vary little by income group and by season. Even though food staples are not naturally dense in mineral content, they already provide a substantial proportion of mineral intakes of poor households. Thus, food staple crops serve as possible candidates for "fortification" through plant breeding. The third section then provides a summary of Graham and Welch (1994) on the positive agronomic benefits to breeding for mineral-dense seeds. A fourth section addresses the issue of the bioavailability of the increased levels of iron and other minerals in staple foods. A fifth section undertakes a review of the present status of activities of the IFPRI-CGIAR effort to improve the dietary quality of staple foods.

2. PATTERNS OF FOOD CONSUMPTION, HOUSEHOLD INCOMES, AND FOOD PRICES

The two primary "food-based" interventions that have been implemented to correct micronutrient malnutrition have been nutrition education and home gardening, the former strategy aimed at providing information as to nutrient-dense foods and the latter strategy directed at production of nutrient-dense foods (thus, programs in these two areas may complement one another). Understanding how household incomes, food prices, and culturally-based preference patterns interact to drive food consumption and nutrient intake patterns can provide crucial background information for designing nutrition education and home gardening programs so that they work as intended.

To demonstrate these points, food consumption patterns that vary by income level and by season are analyzed below for a sample of Philippine farm households.[3] The generalizability of the conclusions reached will be tested through the analysis of several additional data sets at IFPRI over the next year.

AN OVERVIEW OF FOOD EXPENDITURE PATTERNS

Table 1 shows per capita food expenditures, price paid per kilogram, and per capita kilogram consumption by expenditure quintile by seven broad food groups. Note that at the margin as income and food expenditures increase, consumers buy meat, fish, fruits, and

---

[3] For a more detailed analysis of these data with respect to patterns of micronutrient intakes, see Bouis (1991). For a more detailed description of how the data were collected and sample characteristics, see Bouis and Haddad (1990).

snacks. Expenditures for the primary food staples, corn and rice, and for vegetables, increase with income, but the percentage increases are far smaller than for the other food groups.

Such a pattern of food expenditures is consistent with behavior specified in a food demand system proposed by Bouis (1990) in which consumers maximize utility from three food characteristics—energy, variety, and tastes of individual foods. At very low levels of income, considerations of energy and variety drive food consumption choices so that diets consist primarily of staples and vegetables (vegetables being relatively cheap sources of variety). As income increases, marginal utilities from additional energy and variety in the diet fall to the point where considerations of tastes of individual foods drive consumption decisions.

Table 2 presents calorie intake information from four 24-hour recalls of food intakes disaggregated by food group.[4] Calorie consumption from corn and rice is

[4] The information presented in Tables 1-8 are all constructed from these 24-hour recall surveys. A total of 448 households were surveyed four times at four-month intervals.

Table 1—Food expenditures, food prices, and kilograms consumed, by expenditure quintile and food group

Food Group	Expenditure Quintile 1	2	3	4	5	All
Food expenditures (pesos per capita per week)						
Rice	2.32	3.77	4.76	4.51	10.12	5.09
Corn	9.64	9.73	9.19	8.79	4.40	8.36
Other staples	1.46	1.65	1.59	2.47	3.74	2.18
Meat, fish	7.25	9.09	10.77	15.68	24.09	13.37
Vegetables	2.71	2.86	3.58	3.77	3.85	3.35
Fruits, snacks	0.87	2.59	5.34	7.58	10.62	5.40
Cooking ingredients	2.13	3.22	3.46	4.77	4.83	3.68
All	26.37	32.91	38.67	47.59	61.65	41.43
Food prices (pesos per kilogram)						
Rice	5.74	5.98	5.76	5.67	5.59	5.70
Corn	4.36	4.52	4.50	4.46	4.46	4.46
Other staples	2.79	3.39	2.34	3.72	5.35	3.57
Meat, fish	19.58	18.82	20.79	20.63	23.40	21.15
Vegetables	6.36	5.54	7.13	5.97	5.90	6.15
Fruits, snacks	2.83	5.42	11.45	15.22	15.69	11.18
Cooking ingredients	17.21	21.93	19.69	21.52	20.80	20.46
All	6.04	6.72	7.42	8.59	10.15	7.94
Kilograms (per capita per week)						
Rice	0.40	0.63	0.83	0.80	1.81	0.89
Corn	2.21	2.15	2.04	1.97	0.99	1.87
Other staples	0.52	0.49	0.68	0.66	0.70	0.61
Meat, fish	0.37	0.48	0.52	0.76	1.03	0.63
Vegetables	0.43	0.52	0.50	0.63	0.65	0.55
Fruits, snacks	0.31	0.48	0.47	0.50	0.67	0.48
Cooking ingredients	0.12	0.15	0.18	0.22	0.23	0.18
All	4.36	4.90	5.21	5.54	6.08	5.22

Source: International Food Policy Research Institute-Research Institute for Mindanao Culture survey, 1984/85.

Table 2—Family calorie intake per adult equivalent and calories purchased per peso of food expenditure, by expenditure quintile and food group

Data Source and Food Group	Expenditure Quintile 1	2	3	4	5	Quintile 5 Minus Quintile 1
Calorie intakes[a]						
Rice	251	388	511	488	1,111	+860
Corn	1,501	1,469	1,372	1,317	659	-842
Other staples	116	114	147	159	200	+84
Meat, fish	88	118	134	178	283	+195
Vegetables	30	35	35	42	39	+9
Fruits, snacks	41	67	64	71	91	+50
Cooking ingredients	61	81	97	143	178	+117
Rice and corn	1,753	1,857	1,884	1,805	1,770	+17
All others	336	415	477	594	791	+455
All	2,089	2,272	2,361	2,398	2,561	+472
Calories purchased per peso[b]						All Quintiles
Rice	570	563	582	570	604	582
Corn	872	846	858	858	847	857
Other staples	623	526	584	470	396	508
Meat, fish	87	79	84	72	69	77
Vegetables	79	89	72	75	67	76
Fruits, snacks	407	363	351	278	193	300
Cooking ingredients	145	171	180	214	268	197
All	492	440	414	344	286	395

Source: International Food Policy Research Institute-Research Institute for Mindanao Culture survey, 1984/85.

[a] Calories computed from 24-hour recall survey.
[b] Calorie information from 24-hour recall survey and price information from food expenditure survey.

nearly constant across expenditure quintile; as income increases, marginal increases in calorie intakes come from nonstaple sources. Note from the bottom of Table 2 that corn is the cheapest source of calories among the seven food groups. Three pesos worth of corn buys the recommended daily allowance of calories. Table 1 indicates that the per capita food expenditure per day for the lowest income quintile is about four pesos. If three pesos are spent for corn to meet recommended energy requirements, this leaves approximately one peso a day per person for the purchase of nonstaple items.

NUTRIENT ADEQUACY RATIOS BY TOTAL EXPENDITURE QUINTILE AND FOOD GROUP

Table 3 presents the simple sample average of household adequacy ratios for nine nutrients by expenditure quintile. Intakes of iron, calcium, niacin, riboflavin, and thiamin, all appear to be quite strongly and positively correlated with income.[5] Income elasticities would appear to be somewhat lower for calories and proteins, and lowest for vitamin A and vitamin C, the only two nutrients for which a pattern of monotonically increasing adequacy ratios across expenditure quintiles is not in evidence.[6]

---

[5] Income (as measured by total expenditures) increases from approximately US$57 per capita per year to US$239 from lowest to highest expenditure quintile, a percentage increase of 320 percent.

[6] An "income elasticity" measures the percentage change in the quantity of a food or nutrient consumed associated with a given percentage change in household income.

Table 3—Nutrient adequacy ratios by expenditure quintile

Nutrient	Expenditure Quintile 1	2	3	4	5	National All	Average[a]
Calories	0.81	0.88	0.92	0.93	0.99	0.91	0.89
Protein	0.99	1.11	1.13	1.21	1.33	1.15	1.00
Iron	0.66	0.75	0.81	0.87	1.03	0.82	0.92
Vitamin A	1.06	1.08	1.35	1.30	1.38	1.23	--
Vitamin C	0.88	0.85	1.04	1.04	1.04	0.97	0.91
Calcium	0.55	0.65	0.76	0.79	0.90	0.73	0.80
Niacin	0.62	0.80	0.88	0.96	1.35	0.92	1.20
Riboflavin	0.44	0.47	0.52	0.58	0.64	0.53	0.56
Thiamine	0.49	0.59	0.65	0.65	0.87	0.65	0.72

Source: International Food Policy Research Institute-Research Institute for Mindanao Culture survey, 1984/85.

[a] Food and Nutrition Research Institute, Second Nationwide Nutrition Survey, Philippines 1982 (Manila: National Science and Technology Authority, 1984).

On average, the lowest expenditure quintile is consuming the recommended allowances of protein and vitamin A; otherwise, diets are generally deficient in other nutrients. By contrast, the diets of the highest expenditure group would appear to be only seriously deficient in riboflavin. However, these average figures mask a good deal of variation around these means.

MICRONUTRIENT FOOD SOURCES

In drawing conclusions as to the effects of changes in prices and incomes on demand for iron, vitamin A, and vitamin C, it is important to establish which foods or food groups provide specific nutrients. In particular, it is important to see the extent to which nutrient sources are concentrated in particular foods. It has already been seen in Table 2 that calorie consumption comes primarily from rice and corn, although additional calories at the margin are provided by nonstaple foods as income increases.

Table 4 shows that sources of iron are well-distributed among the seven food groups. Meats and fish account for two-thirds of the marginal increase in iron intakes as income increases. The "other staples" and "cooking ingredients" food categories provide the cheapest sources of iron in the diet; two pesos per capita per day would be required to meet recommended *average* daily allowances of iron if consumption were concentrated in these two food groups.[7] It will be argued below

[7] Not only would this be "unappetizing," given revealed preferences for various foods, but a much higher expenditure would be required for women to meet their iron RDA, as can be seen in Table 7.

Table 4—Food sources for iron and iron prices by expenditure quintile and food group

	Expenditure Quintile 1	2	3	4	5	All	Quintile 5 Minus Quintile 1
Milligrams of iron per adult equivalent per day							
Rice	0.53	0.85	1.02	0.93	2.14	1.09	+1.61
Corn	2.31	2.23	2.08	1.98	0.97	1.91	-1.34
Other staples	0.68	0.75	0.91	1.07	1.24	0.93	+0.56
Meat, fish	1.17	1.47	1.69	2.25	3.66	2.04	+2.49
Vegetables	1.16	1.20	1.40	1.39	1.35	1.30	+0.19
Fruits, snacks	0.17	0.30	0.27	0.37	0.37	0.30	+0.20
Cooking ingredients	0.63	0.67	0.74	0.70	0.54	0.65	-0.09
All	6.64	7.47	8.11	8.69	10.27	8.24	+3.63
Percent of RDA[a]	66.0	75.0	81.0	87.0	103.0	82.0	
Milligrams of iron per peso							
Rice	1.87	1.86	1.72	1.75	1.70	1.76	
Corn	1.89	1.83	1.85	1.86	1.79	1.85	
Other staples	5.14	4.94	5.33	4.57	3.77	4.67	
Meat, fish	2.15	1.63	1.86	1.47	1.52	1.70	
Vegetables	4.09	3.95	3.77	3.61	3.38	3.75	
Fruits, snacks	2.36	2.28	2.10	1.60	1.21	1.80	
Cooking ingredients	5.36	4.15	3.83	2.68	1.80	3.51	
All	2.15	2.01	2.00	1.79	1.62	1.91	

Source: International Food Policy Research Institute-Research Institute for Mindanao Culture Survey, 1984/85.

[a] RDA is 10 milligrams.

that this dispersion insulates iron intakes from fluctuations due to changes in prices of specific foods or food groups.

By contrast, as shown in Table 5, sources of vitamin A are relatively concentrated. Vegetables provide 70 percent of vitamin A and meats and fish provide most of the remaining 30 percent, although meat and fish provide more than 50 percent of the marginal increase in vitamin A as incomes increase.[8] Vitamin A is relatively inexpensive in the sense that 57 centavos worth of vegetables typically eaten by the lowest expenditure quintile will provide the recommended daily allowance.

Table 6 provides information on sources and costs of vitamin C. The pattern is very similar to vitamin A in the sense that the recommended daily allowance of vitamin C is obtained relatively inexpensively if sweet potatoes and/or cassava are eaten in significant amounts. Vegetables provide one-half of the vitamin C consumed and almost all of the marginal increase in intakes as income increases. Vitamin C differs from vitamin A in that the "other staples" food category is an important source of vitamin C, while meat and fish are not important sources of vitamin C. Six specific foods (again dominated by horse radish tree leaves) provide about one-half of vitamin C intakes.

---

[8] One specific food, horse radish tree leaves (malunggay leaves in the local language), provides just under 40 percent of total vitamin A intakes.

Table 5—Food sources for vitamin A and vitamin A prices by expenditure quintile and food group

	Expenditure Quintile 1	2	3	4	5	All	Quintile 5 Minus Quintile 1
International Units of vitamin A per adult equivalent per day							
Rice	0	1	1	0	0	1	+ 0
Corn	10	6	0	0	2	4	- 8
Other staples	143	55	246	135	258	167	+115
Meat, fish	1,010	752	949	1,569	1,733	1,202	+723
Vegetables	3,481	3,620	4,607	3,966	4,047	3,945	+566
Fruits, snacks	121	392	229	144	124	202	+ 3
Cooking ingredients	26	28	42	29	36	32	+ 10
All	4,792	4,855	6,073	5,844	6,200	5,553	+1,408
Percent of RDA[a]	106	108	135	130	138	123	
International Units of vitamin A per peso							
Rice	3	3	1	1	0	1	
Corn	4	3	0	0	1	2	
Other staples	871	273	866	465	406	561	
Meat, fish	445	443	418	481	363	428	
Vegetables	7,898	7,007	7,459	6,119	5,310	6,728	
Fruits, snacks	892	863	737	569	322	624	
Cooking ingredients	107	111	118	85	68	97	
All	921	815	895	783	635	810	

Source: International Food Policy Research Institute-Research Institute for Mindanao Culture Survey, 1984/85.

[a] RDA is 4,500 international units.

Table 6—Food sources for vitamin C and vitamin C prices by expenditure quintile and food group

	Expenditure Quintile 1	2	3	4	5	All	Quintile 5 Minus Quintile 1
Milligrams of vitamin C per adult equivalent per day							
Rice	0.0	0.0	0.0	0.0	0.0	0.0	+ 0.0
Corn	1.4	1.1	0.8	1.1	0.3	0.9	- 1.1
Other staples	22.6	16.5	27.1	20.6	22.8	21.9	+ 0.2
Meat, fish	2.4	1.2	1.6	5.1	3.5	2.8	+ 1.1
Vegetables	30.3	35.6	39.7	39.5	42.3	37.5	+12.0
Fruits, snacks	9.3	9.7	8.6	11.4	9.1	9.6	- 0.2
Cooking ingredients	0.0	0.0	0.0	0.1	0.0	0.0	+ 0.0
All	66.0	64.1	77.9	77.9	78.1	72.8	+12.1
Percent of RDA[a]	88	85	104	104	104	97	
Milligrams of vitamin C per peso							
Rice	0.0	0.0	0.0	0.0	0.0	0.0	
Corn	0.7	0.7	0.7	0.8	0.4	0.7	
Other staples	129.2	88.2	98.2	62.6	49.2	81.1	
Meat, fish	1.6	0.9	0.9	1.4	0.9	1.1	
Vegetables	85.7	86.3	80.0	73.7	68.9	78.7	
Fruits, snacks	84.1	50.8	61.5	39.7	22.6	46.8	
Cooking ingredients	0.0	0.0	0.0	0.1	0.0	0.0	
All	15.9	13.2	13.5	11.5	9.5	12.7	

Source: International Food Policy Research Institute-Research Institute for Mindanao Culture survey, 1984/85.

[a] RDA is 75 milligrams.

INTRAHOUSEHOLD DISTRIBUTION OF NUTRIENTS

As shown in Table 7, for all types of family members, there is a very consistent, though small, increase in calorie adequacy ratios as household incomes increase. For iron as well, there is a consistent increase in iron intakes for all types of household members across expenditure quintiles. The percentage increases are much larger for iron than for calories.

A distinguishing feature for iron, however, is that adequacy ratios for females are much lower than for males. Males and females eat approximately the same levels of iron; however, iron requirements for women are considerably higher (about 80 percent higher, according to published Philippine standards) than for men.

Relative to calories and iron, adequacy ratios for vitamin A and vitamin C are reasonably equal across types of household members, although parents consume more vitamin A relative to requirements than do their children. Preschooler vitamin A intakes appear to be strongly correlated with income, while there is no clear association (positive or negative) between intakes of children from the ages of 6 to 19 years of age and income. For vitamin C, with the possible exception of mothers, there is no clear association between intakes and increases in income for a specific type of household member.

VARIATION IN NUTRIENT CONSUMPTION ACROSS SURVEY ROUNDS

The rather startling pattern of nutrient consumption by survey round shown in Table 8 relates less to the seasonality of intakes as to a trend decline across the two

Table 7—Calorie, iron, vitamin A, and vitamin C adequacy levels by type of household member

Expenditure Quintile	Preschoolers	Ages 6-12 Boys	Ages 6-12 Girls	Ages 13-19 Boys	Ages 13-19 Girls	Mothers	Fathers
Calorie adequacy ratios							
1	0.70	0.72	0.71	0.76	0.79	0.96	0.97
2	0.77	0.74	0.73	0.76	0.80	1.03	1.05
3	0.75	0.79	0.79	0.76	0.88	1.10	1.07
4	0.78	0.76	0.77	0.79	0.89	1.09	1.08
5	0.84	0.89	0.88	0.84	0.94	1.16	1.13
All	0.77	0.78	0.77	0.78	0.86	1.07	1.06
Iron adequacy ratios							
1	0.65	0.75	0.70	0.68	0.43	0.53	1.10
2	0.78	0.84	0.65	0.69	0.49	0.57	1.24
3	0.77	0.86	0.80	0.80	0.56	0.62	1.34
4	0.86	0.88	0.84	0.80	0.54	0.66	1.47
5	1.07	1.24	1.03	0.89	0.60	0.76	1.67
All	0.81	0.91	0.78	0.77	0.53	0.63	1.37
Vitamin A adequacy ratios							
1	0.97	1.14	1.02	1.18	0.94	1.17	1.29
2	1.06	0.89	0.92	0.88	0.72	1.13	1.48
3	1.14	1.27	1.16	0.99	0.84	1.49	1.68
4	1.33	1.23	0.92	1.09	0.95	1.37	1.63
5	1.49	1.28	1.19	0.87	0.98	1.52	1.53
All	1.18	1.16	1.03	1.00	0.89	1.33	1.53
Vitamin C adequacy ratios							
1	0.87	0.89	0.95	0.72	0.96	0.85	1.09
2	0.87	0.80	0.73	0.81	0.81	0.84	1.08
3	0.98	0.82	0.98	0.72	0.61	1.06	1.29
4	1.08	0.89	0.70	0.93	1.14	1.06	1.27
5	0.91	1.12	0.78	0.81	0.76	1.11	1.19
All	0.94	0.90	0.84	0.80	0.86	0.98	1.19

Source: International Food Policy Research Institute-Research Institute for Mindanao Culture survey, 1984/85.

Table 8—Household calorie, iron, vitamin A, and vitamin C adequacy levels and percent of households below 80 percent of requirements by survey round

Survey Round	Calories	Iron	Vitamin A	Vitamin C
Adequacy ratios				
1	0.99	1.00	1.95	1.46
2	0.89	0.79	1.24	0.94
3	0.85	0.78	1.03	0.96
4	0.88	0.73	0.71	0.53
All	0.91	0.82	1.23	0.97
Percent of households below 80 percent of requirements				
1	25	42	39	44
2	40	61	59	60
3	47	65	72	72
4	36	69	72	80
All	37	59	60	64

Source: International Food Policy Research Institute-Research Institute for Mindanao Culture survey, 1984/85.

crop years (surveys were conducted four months apart). Calorie intakes behave as might be expected a priori. Percent of households below 80 percent of requirements is lowest during the first and fourth rounds, coinciding with the corn harvest and lowest corn prices. Average calorie adequacy ratios show no apparent seasonal association; calorie intakes fell somewhat during the second through fourth round surveys, which, in part, could be associated with a 10-15 percent decline in incomes and food expenditures.

Iron adequacy ratios show a similar pattern as for calories with two important differences. First, there is a greater decline in iron intakes in the second through fourth round surveys as compared with the decline in calories; one would expect nonstaple food expenditures (which are rich sources of iron) to decline more rapidly than staple food expenditures as income falls. Second, the trend increase in percent of households whose iron intakes are below 80 percent of requirements continues into the fourth round for iron, instead of reversing itself as is the case for calories.

Finally, Table 8 shows that vitamin A and vitamin C intakes in the fourth round are only one-third the intakes of these micronutrients in the first round! It is the green, leafy vegetables that provide the bulk of the vitamin A from vegetable sources. Prices of green, leafy vegetables, which are more expensive than other types of vegetables, increased substantially between the first and fourth survey rounds. Up to three-fourths of consumption of green leafy vegetables comes from own-production. It is unclear the extent to which the decline in consumption is due to declining production (for example, due to poor weather leading to higher prices), or due to the sale of a higher percentage of home production of green, leafy vegetables, given more favorable market prices.

CONCLUSIONS AS TO APPROPRIATE NUTRITION INTERVENTIONS

The essential difference between demand for calories and demand for micronutrients is that consumers consciously take care to minimize fluctuations in calorie consumption, but are unaware of fluctuations in their consumption of micronutrients. Thus, despite the fact that calorie consumption is concentrated in two foods (corn and rice), consumers react to increases in prices of these staples, either by switching to other calorie-dense staples or reducing expenditures for nonstaples and nonfoods to protect (to a large extent if not completely) acceptable levels of calorie consumption. Staple grains are an important source of iron, but not of vitamin A and vitamin C. Therefore, even at low-income levels, a minimal amount of iron is consumed (albeit not the most bioavailable form of iron).

Despite the fact that consumers are likely unaware of their iron consumption, iron consumption is also relatively immune to food price fluctuations because iron sources are so diverse, and because staples provide significant amounts of iron. Nonstaple foods are important sources of iron. Because nonstaple food income elasticities are high, iron income elasticities are high. Calorie income elasticities are also positive because of the high propensities for nonstaple foods. However, calorie-income elasticities are much lower than iron-income elasticities, due to the fact that nonstaples are low-density calorie sources (nonstaples being high-density iron sources).

Demand behavior for vitamin A and vitamin C is fundamentally different from iron because (1) intakes for these two nutrients are concentrated in relatively few foods, primarily vegetables, and (2) vegetables have low-income elasticities, being relatively inexpensive sources of variety in the diet (although, in the case of vitamin A, high-income elasticity meats are an important secondary source of vitamin A), and (3) staple grains have virtually none of these vitamins. Because of this concentration and because consumers are unaware of their vitamin intakes, intakes may fluctuate widely with prices, even though it is possible to satisfy daily requirements relatively inexpensively.

Programs to educate consumers about the importance of meeting recommended daily allowances of vitamin A and vitamin C and about commonly eaten sources of these nutrients, then, would seem to have the potential for improving intakes. For this Philippine population, because so much vitamin A and vitamin C comes from own-production, extension programs to promote growing green, leafy vegetables not only would provide households with a ready supply of these nutrients (unless they sell additional production), but increased production could bring the local price down.

By contrast, it is much more difficult to see how these types of education and extension programs could be effective in increasing iron intakes, if only because sources of iron are so diverse in the diet and, on average, these sources of iron are expensive. While the estimated iron-income elasticity is relatively high (suggesting that policies/programs that increase income may solve the problem without resort to health/nutrition interventions), iron adequacy ratios for low-income groups are quite low. A 320 percent increase in income (an absolute increase in income of only $180 per capita) from lowest expenditure to highest expenditure quintile moves the average adequacy ratio from 0.66 to 1.03. However, these household averages mask large differences in requirements between males and females; even at high income levels (for this sample of households), iron intakes of females are inadequate (see Table 7). If future increases in national aggregate income will not be disproportionately directed to the poor, then the problem of low iron intakes will take many decades to solve through income alone.

Fortification and/or supplementation interventions may be the best policies for solving the low iron intake problem in the short-run, particularly for women and young children, but plant breeding offers a much lower-cost, more easily sustainable long-run solution as discussed below.

3. PLANT NUTRITION AND MINERAL-DENSE SEEDS

PREVIOUS CGIAR EXPERIENCE WITH BREEDING FOR DIETARY QUALITY

There is previous experience within the CGIAR in breeding for nutritional characteristics. In the early 1970s, a major breeding program was begun at the International Maize and Wheat Improvement Center (CIMMYT) to produce a high-quality protein (lysine) maize. At the time, conventional wisdom among nutritionists was that quality protein was a key limiting nutrient to better nutrition in developing countries.

The historical record of this breeding program is reviewed by Tripp (1990), who considers the overall effort to have been a major misallocation of resources. The primary problem was that the original genetic material that contained high-lysine was low-yielding. It took some time to develop varieties that were both high-lysine and high-yielding. However, the high-lysine, high-yielding varieties never equalled the performance of the best-yielding, highest-profit maize varieties, so that farmer adoption was a major constraint. Moreover, nutritionists have long since concluded that quality protein is not a key limiting nutrient to better nutrition, so that the impetus to further breeding for nutritional objectives has been lost.

Therefore, when the idea of breeding for micronutrient content was first broached with individual scientists within the CGIAR in early 1993, the proposal was generally met with skepticism, although with a few exceptions. Notwithstanding the fact that there was virtually no institutional knowledge of genotype variation in micronutrient content of crop varieties developed by the CGIAR Centers, the presumption among those CGIAR scientists contacted was either that there again would be a trade-off between plant yield and nutritional value, or, at best, that there would be no correlation with yield and that adding an additional breeding objective (nutritional quality) would slow down the overriding breeding objective of higher and more stable crop yields.[9]

However, this attitude among a core of CGIAR plant breeders had changed dramatically by late 1993 upon learning about research undertaken by Robin Graham and others to improve *plant nutrition* by breeding for crops with improved efficiency in the uptake of minerals from "deficient" soils and which loaded high amounts of these minerals into plant seeds. This work was aimed primarily at improving the productivity of crop production in developed countries (Australia, in the case of Robin Graham's research; the soils in Australia are among the most mineral "deficient" in the world).

---

[9] It probably did not help matters that the subject was broached by an economist (the author) with little knowledge of plant physiology and plant breeding and no formal training in human nutrition.

With regard to the potential of this strategy for improving human nutrition, some long-standing collaboration had been ongoing between Robin Graham and Ross Welch and others at the Plant, Soil, and Nutrition Laboratory (run by USDA-ARS and located on the Cornell University campus), again primarily motivated by a concern for improved mineral intakes in developed countries (the United States in the case of the PSNL). From the point of view of the Waite-PSNL collaboration, the IFPRI-CGIAR project became the occasion for the possible application of this work to the much more serious mineral deficiency problems found in developing countries. From the point of view of the CGIAR Centers, the Waite-PSNL collaboration represents a wealth of scientific information previously untapped for possibly improving the nutrition of CGIAR-released crop varieties, with possible spinoff benefits for human nutrition.

AGRONOMIC ADVANTAGES OF MINERAL-DENSE SEEDS

What follows is a summary of the main points made in a keynote paper presented by Robin Graham and Ross Welch at an organizational workshop held last January 10-12 in Annapolis, Maryland, U.S.A., outlining the reasons to expect positive impacts on plant yields of crop varieties that are efficient in the uptake of mineral micronutrients from soils and that load high amounts of these minerals into seeds. Readers are referred to that paper for descriptions of studies and experiments undertaken to support the conclusions cited.

1. A low amount of a trace mineral in a "deficient" soil is not the problem, but rather the key to better plant growth is making more of the trace mineral that is already in the soil "available" to the plant.

A soil is said to be deficient in a nutrient when addition of fertilizer containing that nutrient produces better growth. However, the amount of a mineral micronutrient added to a soil needed to produce better growth is usually small compared to the total amount of that mineral found in the soil by complete analysis. It may be concluded that only a small part of the nutrient in the soil is "available" to plants. An alternative view, therefore, is that there is a genetic deficiency in the plant, rather than a deficiency in the soil.

Tolerance to micronutrient-deficient soils, termed *micronutrient efficiency*, is a genetic trait of a genotype or phenotype that causes it to be better adapted to, or yields more in, a micronutrient deficient soil than can an average cultivar of the species (Graham 1984). Growing zinc-efficient plants on zinc-deficient soils, for example, represents a strategy of "tailoring the plant to fit the soil" in contrast with the alternative strategy of "tailoring the soil to fit the plant" (terminology according to Foy [1983]).

Nearly all micronutrient efficiency traits so far studied arise from a superior ability to extract the limiting micronutrient from the soil, rather than a capacity to survive on less of that micronutrient. Rye is an example of a highly nutrient-efficient crop for which few of the notoriously deficient soils of South Australia is low enough in nutrients to limit its production.

It is well understood that depletion of soil nitrogen takes only a few years if there is no replacement. Thus, it is pointless to breed for greater tolerance to nitrogen-deficient soils. By contrast for mineral micronutrients, depletion may take hundreds or thousands of years, or may likely never occur at all, owing to various inadvertent additions and other processes (for example, minerals carried in windblown dust [Graham 1991]). It is logical, then, to concentrate breeding efforts toward producing micronutrient-efficient varieties for minerals that are required in low amounts, for which soil *availability* is low, but for which there are large reserves in the soil.

2. Micronutrient-deficient soils are widespread throughout developing countries.

Iron is the fifth most abundant element in the earth's crust, but the fraction of soil iron that may be in soluble forms suitable for absorption by plants may be only 10^{-13} of total soil iron. Thus, depletion of soil iron is never an issue, but a matter of the amount of chemical attack in the soil to dissolve iron that each plant genotype can mount.

Small grain cereals (for example, wheat and rye) have a highly-efficient mechanism for solubilizing and extracting iron from the soil. In contrast, upland rice, maize, sorghum, and grain legumes are, on the whole, very sensitive to iron deficiency that is widespread (Katyal and Vlek 1985).

Paddy rice is a special case, where the soil is flooded for much of the growing season. The low oxygen status in the soil leads to more of the soil iron becoming soluble and uptake of iron into the paddy rice crop is quite high. When such soils become acidic as a result of use of nitrogen fertilizer, the solubility increases dramatically and toxic levels are found in the rice plant. Nevertheless, little of the foliar iron ends up in the grain of modern cultivars. In this case, iron is already in the plants in large amounts and the breeding objective is phloem translocation efficiency.

Zinc deficiency is probably the most widespread micronutrient deficiency in cereals. Sillanpää (1990) found that 49 percent of a global sample of 190 soils in 25 countries were low in zinc. Unlike other micronutrients, it is a common feature of both cold and warm climates, drained and flooded soils, acid and alkaline soils, and both heavy and light soils.

3. Efficiency in the uptake of mineral micronutrients from the soil is associated with disease resistance in plants and so decreased use of fungicides.

Good nutritional balance is as important to disease resistance in plants as it is in humans. Micronutrient deficiency in plants greatly increases their susceptibility to diseases, especially fungal root diseases of the major food crops. The picture emerging from physiological studies of roots spanning four decades is that the elements phosphorus, zinc, boron, calcium, and manganese are all required in the *external environment* of the root for membrane function and cell integrity. In particular, phosphorus and zinc deficiencies in the *external* environment promote leaking of cell contents such as sugars, amides, and amino acids, which are chematoxic stimuli to pathogenic organisms. In the case of zinc, a high internal zinc content did not prevent leakiness due to a deficiency of zinc external to the membrane.

It appears that micronutrient deficiency predisposes the plant to infection, rather than the infection through its effect on root pruning causing the deficiency (Graham and Rovira 1984; Sparrow and Graham 1988; Thongbai et al. 1993). Breeding for micronutrient efficiency can confer resistance to root diseases that had previously been unattainable. This means a lower dependence on fungicides.

4. Micronutrient-efficient varieties grow deeper roots in mineral deficient soils and so are better able to tap subsoil water and minerals.

When topsoil dries, roots in the dry soil zone (which are the easiest to fertilize) are largely deactivated and the plant must rely on deeper roots for further nutrition. Roots of plant genotypes that are efficient in mobilizing surrounding, external minerals, not only are more disease resistant, but are better able to penetrate deficient subsoils and so make use of the moisture and minerals contained in subsoils. This reduces the need for fertilizers and irrigation.

5. Micronutrient-dense seeds are associated with greater seedling vigor that, in turn, is associated with higher plant yield.

An important function of the seed is to supply the young seedling with minerals until it has developed a root system large enough to take over this role, but in nutrient poor soils, seed reserves may be insufficient to last while the extra roots are developed to compensate for the low mineral supply. The result is a transient and critical period of deficiency when the seedling is particularly vulnerable. Pathogens and weeds may gain an advantage not otherwise given, so that the plants never regain lost potential.

6. There is substantial genetic variability in the efficiency of uptake of mineral micronutrients from deficient soils and in nutrient loading into seeds; micronutrient efficiency is controlled by major, single gene inheritance.

The concentration and content of mineral micronutrients in seeds are the result of transport via living tissues (the phloem) from vegetative parts of the plant. Thus, seed density depends on both the micronutrient density of vegetative tissues and on the efficiency of the transport process itself. Both can be under genetic control, but there is considerable homeostasis built into the transport process so that even where the soil and vegetative plant are high in micronutrients, the levels in the seed are always relatively low. An average view of genetic variation in micronutrient density is probably of the order of a factor of three, while their vegetative parts may vary perhaps 100 times more than that.

By far the most extensive survey of efficiency factors was carried out at the International Rice Research Institute by Ponnamperuma (1982). Over a period of 10 years, some 80,000 lines from the world collection were screened for types tolerant of a number of soil stresses, including micronutrient deficiencies. Tolerant types gave a yield advantage of about two tons per hectare under any of seven different soil limitations. Ponnamperuma noted that zinc deficiency was widespread in wet rice and iron deficiency in dryland rice.

Linkage of zinc efficiency to other efficiency traits (for example, manganese) is poor, suggesting independent mechanisms and genetic control not linked to gross root system geometry. Zinc-efficient genotypes absorb more zinc from deficient soils, produce more dry matter and more grain yield, but do not necessarily have the highest zinc concentrations in tissue or grain. Although high grain zinc concentration also appears to be under genetic control, it is not tightly linked to agronomic zinc efficiency traits and may have to be selected for independently.

4. PLANT BREEDING AND BIOAVAILABILITY

Table 4 shows that the two basic staples, rice and corn, provide approximately 40 percent of the total iron intake for the Philippine population studied. Thus, if the presently low iron content of food staples could be increased by a factor of say 3.5 (say from 12 to 42 parts per million), this would double iron intakes. However, would this double the amount of bioavailable iron?

FAO/WHO recommends that people who obtain less than 10 percent of their calories from animal foods (this applies to the surveyed Philippine population as shown in Table 2) need more iron because perhaps only 5 percent of total intake is absorbed.[10] While doubling iron intakes would not allow the surveyed Philippine females to attain this RDA, particularly at very low income levels, there is no reason to think that the degree of absorption of additional iron would be lower than the average rate of absorption, unless the level of phytin in the grain increases as iron is increased. Thus, bioavailable iron could also double, which should be of substantial benefit.

Phytin, being the primary storage form of phosphorus in most mature seeds and grains, is an important compound required for early seed germination and seedling growth (Welch 1986). Phytin plays an important role in determining mineral reserves of seeds and, thus, contributes to the viability and vigor of the seedling produced (Welch 1986, 1993). Selecting for seed and grain crops with substantially lower phytin content could have an unacceptable effect on production, especially in regions of the world having soils of low phosphorus status and/or poor micronutrient fertility (Graham and Welch 1994).

Such attempts to significantly lower the antinutrient content of seeds and grains requires a major shift in seed or grain composition. Because most of the antinutrients known to occur in seeds and grains are major organic constituents of these organs, they may play additional, but yet unrecognized, beneficial roles in plant growth and human health. Therefore, a breeding strategy of attempting to increase iron bioavailability by reducing antinutrient content is not recommended (Graham and Welch 1994).

---

[10] The suggested RDA for healthy, menstruating females is 28 milligrams per day, and for healthy, adult males, is 9 milligrams per day (as quoted from Graham and Welch 1994).

Some reports show that certain amino acids (such as methionine, cysteine, and lysine) enhance iron and/or zinc bioavailability. These amino acids occur in many staple foods, but their concentrations are lower than those found in meat products. It may not be necessary to substantially increase the concentration of these amino acids in plant foods to have a positive effect on iron and zinc bioavailability in humans. Iron and zinc occur only in micromolar amounts in plant foods, so only micromolar increases in the amounts of these amino acids may be required to counteract the negative effects of antinutrients on iron and zinc bioavailability. These amino acids are essential nutrients for plants as well as for humans, so relatively small increases of their concentrations in plant tissues should not have adverse consequences on plant growth. The optimal breeding strategy from the point of view of bioavailability may be to increase levels of promotor compounds (Graham and Welch 1994).

5. POST WORKSHOP REVIEW OF ACTIVITIES ON THE AGRICULTURAL TECHNOLOGY SIDE OF THE PROJECT

Screening for promising germplasm will commence soon. Three Centers are involved and five crops: The International Rice Research Institute (IRRI) in the Philippines (rice), the International Center for Improvement of Maize and Wheat (CIMMYT) in Mexico (corn and wheat), and the International Center for Tropical Agriculture (CIAT) in Colombia (beans and cassava). The organizational workshop held last January was the first opportunity for plant breeders, plant nutritionists, human nutritionists, and economists (from inside and outside the CGIAR) to get together to discuss the viability of this approach. A great deal of enthusiasm was generated at the meeting for this strategy (in part, for reasons already discussed above).

For example, a CIMMYT wheat breeder based in Turkey, where soils are particularly zinc-deficient, went to Australia in 1993 to learn about ongoing plant research there, where growing conditions and constraints to improved productivity are similar to those in Turkey. He gave a presentation at the workshop in which he estimated that, if the Australian zinc-dense seed varieties were adapted to growing conditions in Turkey, Turkish wheat farmers would save $100 million *annually* in reduced seeding rates alone (seeding rates could be reduced from an average of 250 to 150 kilograms per hectare on 5 million hectares; a ton of wheat sells for about US$200 on the world market). This does not count the benefit to yield, or the potential benefit of improved zinc status in humans.

Draft proposals were discussed to undertake a coordinated research project over the next five years for the five crops mentioned above, with specific activities identified to be undertaken in five locations—the three CGIAR Centers, IRRI, CIMMYT, and CIAT, the Waite Agricultural Research Institute in Adelaide, Australia, and the Plant, Soil, and Nutrition Laboratory (PSNL) in Ithaca, New York.[11] It was generally agreed that this plant breeding strategy could be successful only through such a global network involving close cooperation between Waite, PSNL, the CGIAR Centers, and developing country national agricultural research institutions. The CGIAR does not have the requisite know-how or equipment (certainly in the area of bioavailability and, it turns out, in the area of screening

[11] Several USDA-ARS scientists took part in the workshop, with heavy participation from the PSNL.

material for trace minerals) for some of the more "upstream" research that needs to be undertaken. The CGIAR has an obvious comparative advantage in terms of (1) the amount of germplasm available for screening, (2) undertaking the task of incorporating promising micronutrient-dense characteristics into existing elite lines through breeding, and (3) dissemination of the nutritionally-improved elite material to a large number of countries. While a formal review of finalized proposals has yet to be undertaken by six members of the project advisory committee (representing several scientific disciplines) who attended the workshop, they were generally enthusiastic about the plant improvement approach.

Thus, very significant progress has been made in terms of (1) putting much of the requisite network of people and institutions in touch with one another, (2) obtaining consensus among an interdisciplinary group of distinguished scientists that this research strategy looks promising in terms of its scientific feasibility and potential for improving human nutrition in developing countries, and (3) obtaining agreement on specific activities that scientists and institutions must undertake in coordination to make this happen.

What is lacking now is medium- to long-run funding to proceed with the full proposed research agenda over the next five years. Draft proposals amounting to US$5 million were discussed at the workshop.[12] The Office of Health and Nutrition of USAID has committed US$1 million for this work to be spent by the CGIAR Centers in collaboration with developing-country agricultural research institutions.

---

[12] This included bioavailability studies to be conducted at PSNL, although these studies did not involve the use of human subjects, which is quite expensive.

TIMING AND COSTS RELATIVE TO ALTERNATIVE SUPPLEMENTATION AND FORTIFICATION STRATEGIES

Because a plant breeding strategy is sometimes dismissed as being too expensive and taking too long, it is perhaps worthwhile to provide some perspective on costs and on the lag between initial plant breeding activities and adoption of any new technologies that are developed. With respect to the timing issue, plant breeders associated with the project estimate that, if the genetic inheritance is relatively simple as argued by Graham and Welch (1994), improved varieties could be developed within four years. This time could double if genetic inheritance turns out to be unexpectedly complex and linked to undesirable traits. In either case, two to three years need to be added for national government agricultural research programs to test the new varieties before their release. Thus, an optimistic estimate is that six years would be required before nutritionally-improved varieties would begin to be produced by farmers in developing countries.[13]

---

[13] Just as for human nutrition, the importance of micronutrients for plant nutrition and the specific mechanisms involved are much better understood today than 10-15 years ago. Indeed, this existing base of scientific knowledge can be thought of as a prerequisite (a 10-15 year first step now completed, although there is much still to be learned), which will inform and accelerate the proposed plant breeding work. Similarly, putting the network of institutions and scientists in place and coming to agreement on a work plan (which will commence this August) has been an 18-month process, a second step that is also now completed.

In this sense, then, implementation of the plant breeding strategy has not only already begun, it is mid-way in the overall process. The 6-10 years left for what is widely regarded as a "long-run" strategy to come to fruition may be compared with the time involved to implement "short-run" strategies, such as large-scale nutrition education, fortification, or supplementation programs. Even for these "immediate impact" types of projects, planning, obtaining approval for funding, training, and other logistical arrangements may take a number of years (although usually fewer than six) before an initial nutrition impact is made on a target population.

Turning to costs, as pointed out in the introduction, a drawback of supplementation and fortification programs is that, by not addressing the underlying causes of low micronutrient intakes, they inherently involve recurrent annual expenditures. Levin et al. (1993) estimate the lower-bound cost of iron supplementation at $2.65 per person per year, when all administrative costs are taken into account.[14] A lower-bound estimate for iron fortification is 10 cents per person per year. Consider a populous country, such as India, where as many as 28 million pregnant women may be anemic in any given year out of a total population of 880 million. These figures imply that treating one-half of the anemic pregnant women in any one year through a well-targeted supplementation program would cost $37 million per year. A fortification program reaching one-half of the population would cost $44 million per year. In view of the fact that these cost figures are *recurrent annual* costs for one country, it is not difficult to understand that the one time costs proposed for plant breeding are low indeed, in view of the potential impact that such a strategy can have on micronutrient intakes.[15]

To be sure, there is no guarantee that the $5 million price tag suggested above for plant breeding over a five-year period will be successful within that period of time, nor does it count costs of adapting any elite lines that are developed to local conditions in specific countries. One can imagine that there will be unforeseen problems and costs associated with plant breeding not mentioned here. Therapeutic doses of iron from supplementation and

---

[14] All monetary figures quoted are in U.S. dollars.

[15] Again, this in no way implies that resources spent on supplementation and fortification are poor investments. The benefits may be quite high.

fortification programs may be higher than the additional iron likely to be added to food staples through plant breeding.

Nevertheless, whatever refinements are necessary to these comparative cost estimates, there is no arguing with the fact that the base, fixed costs of plant breeding are sufficiently low, that cost considerations are overwhelmingly on the side of a plant breeding strategy as compared with supplementation and fortification.

6. BEYOND THE END-OF-DECADE GOALS

Because of the comparatively long lead times involved in bringing the results of plant breeding research to bear on the mineral deficiency problems in humans, and even if the necessary resources are found to implement this strategy in a proper way, unfortunately these efforts will not contribute to meeting the mid-decade and end-of-decade goals for reducing micronutrient malnutrition set out in the World Declaration on Nutrition and endorsed by 158 countries at the International Congress on Nutrition. However, the timing of the IFPRI-CGIAR project is such that the mineral-dense seed technologies would come "on-line" just after the major push to meet the end-of-decade goals through higher-cost strategies has run its course.

While plant breeding will not eliminate the need for supplementation, fortification, and nutrition education programs in the future, this strategy does hold promise for significantly reducing expenditures required for these higher-cost, short-run programs by significantly reducing the number of people requiring treatment. It would seem prudent to invest now in a plant breeding strategy to sustain the gains made by the end of the decade and to maintain momentum for further reductions in iron and other mineral deficiencies.

In closing, the key issues are not those of cost, or whether plant breeders eventually will be successful in developing micronutrient dense seeds if the modest resources required are found to develop them. Rather the two key issues are: (1) will the agronomic advantages of the mineral-dense seeds be sufficiently strong that they will be widely adopted by farmers in developing countries?;[16] and (2) will the additional nutrients contained in the seeds be of a sufficient magnitude and sufficiently bioavailable so as to have an appreciable impact on micronutrient status? As outlined in this paper, there is much scientific evidence to be optimistic, even excited, on the first count. There are good reasons to be optimistic on the second count as well.

[16] In which case, the benefits to farmers in terms of reduced input costs and higher yields will justify any research costs, quite apart from any direct benefits for human nutrition.

REFERENCES

Bouis, H. E. 1990. A food demand system based on demand for characteristics: If there is curvature in the Slutsky Matrix, what do the curves look like and why? International Food Policy Research Institute, Washington, D.C..

________. 1991. Household-level demand for micronutrients: An analysis for Philippine farm households. International Food Policy Research Institute, Washington, D.C.

Bouis, H. E., and L. J. Haddad. 1990. *Agricultural commercialization, nutrition, and the rural poor: A study of Philippine farm households*. Boulder, Colo., U.S.A.: Lynne Rienner Publishers.

FRNI (Food and Nutrition Research Institute). 1984. Second nationwide nutrition survey Philippines 1982. Manila: National Science and Technology Authority.

Foy, C. D. 1983. Plant adaptation to mineral stress in problem soils. *Iowa State Journal of Research* 57: 355-391.

Graham, R. D. 1984. Breeding for nutritional characteristics in cereals. *Advances in Plant Nutrition* 1: 57-102.

________. 1991. Breeding wheats for tolerance to micronutrient deficient soil: Present status and priorities. In *Wheat for the Nontraditional warm areas*, ed. D. A. Saunders, 315-332. Mexico City, Mexico: Centro Internacional de Mejoramiento de Maiz y Trigo.

Graham, R. D., and A. D. Rovira. 1984. A role for manganese in the resistance of wheat to take-all. *Plant Soil* 78: 441-444.

Graham, R. D., and R. M. Welch. 1994. Breeding for staple-food crops with high micronutrient density: Long-term sustainable agricultural solutions to hidden hunger in developing countries. Paper prepared for presentation at an organizational workshop on Food Policy and Agricultural Technology to Improve Diet Quality and Nutrition, Annapolis, Md., U.S.A., January 10-12.

Katyal, J. C., and P. L. Vlek. 1985. Micronutrient problems in tropical Asia. *Fertilizer Research* 7: 69-94.

Levin, H. M., E. Pollitt, R. Galloway, and J. McGuire. 1993. Micronutrient deficiency disorders. In *Disease control priorities in developing countries*, ed. D. Jamison, W. Mosley, A. Measham, and J. Bobadilla. New York: Oxford University Press.

Ponnamperuma, F. N. 1982. Genotypic adaptability as a substitute for amendments on toxic and nutrient-deficient soils. In *Plant nutrition 1982. Proceedings of the Ninth International Plant Nutrition Colloquium*, ed. A. Scaife, 467-473. Slough: Commonwealth Agricultural Bureaux.

Sillanpää, M. 1990. *Micronutrient assessment at the country level: An international study*. FAO Soils Bulletin 63. Rome: Food and Agriculture Organization of the United Nations.

Sparrow, D. H., and R. D. Graham. 1988. Susceptibility of zinc-deficient wheat plants to colonization by *Fusarium graminearum* Schw. Group 1. *Plant Soil* 112: 261-266.

Thongbai, P., R. J. Hannam, R. D. Graham, and M. J. Webb. 1993. Zn nutrition and rhizoctonia root rot of cereals. *Plant Soil* (in press).

Tripp, R. 1990. Does nutrition have a place in agricultural research? *Food Policy* 15 (6): 467-474.

Welch, R. M. 1986. Effects of nutrient deficiencies on seed production and quality. *Advances in Plant Nutrition* 2: 205-247.

________. 1993. Zinc concentrations and forms in plants for humans and animals. In AD Robson, ed, *Zinc in soils and plants*, ed. A. D. Robson, 183-195. Dordrecht, Netherlands; Boston, Mass., U.S.A.; and London: Kluwer Academic Publishers.