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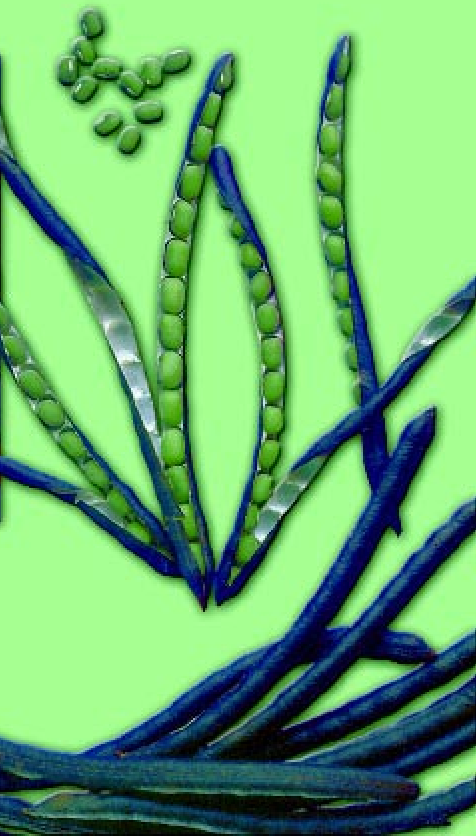

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AVRDC—the World Vegetable Center is an international not-for-profit organization committed to ensuring the world's food security through research, development, and training.

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1 Introduction

1.1 Background

Iron deficiency continues to be the most prevalent micronutrient disorder worldwide. The United Nations Administrative Committee on Coordination/Sub-Committee on Nutrition (ACC/SCN) estimates that as many as 3.5 billion people in the developing world may be affected. Asia has the highest prevalence of anemia, the most serious form of iron deficiency (ACC/SCN, 2001). Most severely affected are women at the reproductive age and children. In South Asia, approximately 88% of all pregnant women and 63% of children between 5 and 14 years of age are believed to be anemic (ACC/SCN, 2001).

In children, anemia is associated with impaired physical and cognitive development. In adults, anemia leads to weakness and fatigue, and therefore to lower productivity and reduced capacity for physical work. Significant human and economic losses for economies are thus consequences of iron deficiencies. Productivity losses for India range from 5 to 17% in wage labor (Weinberger, 2002a), 17% in heavy labor, and 5% in blue-collar work (Horton, 1999). For economies as a whole, overall losses have been estimated between 0.9% (ACC/SCN, 2000) and 1.25% of GDP (Horton, 1999). In developing countries such as India, where per capita GNP is US$450 and over 30% of its population live in poverty (World Bank, 2002), reducing iron deficiency is an important means to increase productivity and reduce poverty.

Different strategies to fight iron deficiencies have been identified. These include: 1) distribution of iron supplements; 2) fortification of staple foods such as salt or flour; and 3) food-based approaches used in combination with nutrition education programs. While donors in the past have favored supplementation and fortification strategies (Ruel, 2001), these approaches are beset with many problems. Supplementation of iron, for example, is difficult to supervise, particularly in regions where infrastructure is missing (ACC/SCN, 2000). Fortification of food, although a cost-effective way to increase nutrient availability to large population groups, requires effective management that includes advocacy, communications, regulation and quality control, along with monitoring and evaluation (FAO/ILSI, 1997).

Food-based approaches usually are more long-term oriented than the former two. Strategic choices for food-based approaches include: 1) increasing production of micronutrient-rich foods; 2) increasing intake of micronutrient-rich foods; 3) improving bioavailability of micronutrients; and 4) developing cultivars that increase density of micronutrients, decrease content of inhibitors, or increase content of substances that promote absorption. The aims of these strategies are to increase the population’s access to micronutrient-rich foods, as well as to increase the consumption and the amount of micronutrients that can be absorbed and utilized by the body (Ruel, 2001). Enhancing the bioavailability of iron can be achieved by reducing the intake of inhibitors, such as phytates in tea, or by increasing the intake of ascorbic and other organic acids (Allen and Ahluwalia, 1997; AVRDC, 1999).

There are certain advantages associated with food-based approaches. Firstly, they are considered to be more sustainable. Secondly, foods provide several essential micronutrients, simultaneously addressing a combination of deficiency problems. Thirdly, physiological interactions between vitamins and minerals in foods can enhance the body's ability to absorb essential micronutrients. And fourthly, foods can be used in a wide range of forms (whole, processed, fortified, or a combination thereof) to overcome micronutrient deficiencies (Vijayalakshmi and Amirthaveni, 1999b). Food-based approaches, therefore, may be the strategy of choice after therapeutic treatment through supplementation is no longer needed (Howson et al., 1998).

The potential for food-based approaches to combat iron deficiencies seems to be high. Iron deficiency can have several causes, such as inadequate iron intake, reduced bioavailability of dietary intake, or increased need for iron. The most important determinant of anemia at every stage in the life cycle of persons living in Asia and Latin America, except during pregnancy and infancy, was found to be the diet, particularly bioavailability of iron (Gillespie and Johnston, 1998). For developing countries, researchers agree that poor quality rather than quantity of diets is the key determinant of impaired micronutrient status, including iron deficiency (Allen, 1993; World Bank, 1994).

In India, total dietary intake and bioavailability of iron is low among poor households. On an average, they consume only about 55% of the required iron intake per adult equivalent (Weinberger, 2001a). Furthermore, in India's predominantly vegetarian households, up to two-thirds of this iron may come from cereals (AVRDC, 2001), thus contributing to nutrition in the form of nonheme iron. The bioavailability of nonheme iron is much lower than that of heme iron, with absorption rates ranging from 5 to 10% (UNICEF/UNU/WHO/MI, 1998; Gopalan et al., 2000).

Much less is known concerning the efficiency of food-based approaches to reduce anemia based on nonheme iron intake from plant sources compared to heme iron intake from animal sources (Ruel and Levin, 2000). For projects focusing on increasing the intake of vegetables, some positive impact on the vitamin A status has been shown, for example in Central Java (de Pee et al., 1998) and in India (Chakravarty, 2000). For heme iron from animal sources, positive effects on the reduction of iron deficiency anemia have been established (Carrasco Sanez et al., 1998).

1.2 Cooking effects on iron bioavailability

The bioavailability of iron in vegetables can be enhanced by cooking (Achillefs and Lee, 1995). This enhancing effect has been studied for a number of vegetables at AVRDC (AVRDC, 1996). Among 45 vegetables studied, the following three types were observed: 1) low availability of iron with or without cooking; 2) low availability of iron before cooking but high after cooking; and 3) high availability of iron with or without cooking. The representative vegetables for each group are kangkong (*Ipomoea aquatica*), cabbage (*Brassica oleracea* var. *capitata*), and tomato (*Lycopersicon esculentum*), respectively (Yang et al., 2002).

Preliminary studies suggested that the enhancing effect on iron bioavailability is independent of vitamin C content in the vegetables. In the case of cabbage, the enhancing effect through cooking could be due to the reduction of the iron-polyphenolics interaction, which commonly occurs during plant cell destruction. The nature of the enhancing factors in these vegetables can be similar to the effect of EDTA, which stabilizes iron when it is released from cells (AVRDC, 1999; AVRDC, 2000).

Studies carried out to investigate the enhancing effect of vegetables can be extended to other iron rich foods when they are cooked together. Mungbean (*Vigna radiata* var. *radiata*) was selected as an iron source due to its high iron content and because it is a popular pulse in the South Asian diet. Figure 1 summarizes the enhancing effect of selected vegetables on iron bioavailability of mungbean when they are cooked separately and together. Cabbage, tomato, moringa (*Moringa oleifera*), kale (*Brassica carinata*), and sweet pepper (*Capsicum annuum*) were added with raw and soaked mungbean and then boiled together. Tomato and moringa leaves were found to be most effective in enhancing the iron bioavailability of mungbean. The dialyzable iron can be as high as over 20 µg per 20 g of a mixture of mungbean and vegetables after cooking. Similar results were observed when these vegetables were cooked with other legumes such as soybean and lima bean. No enhancing effect, however, was observed when they were cooked with cereals such as rice and wheat flour (AVRDC, 2000).

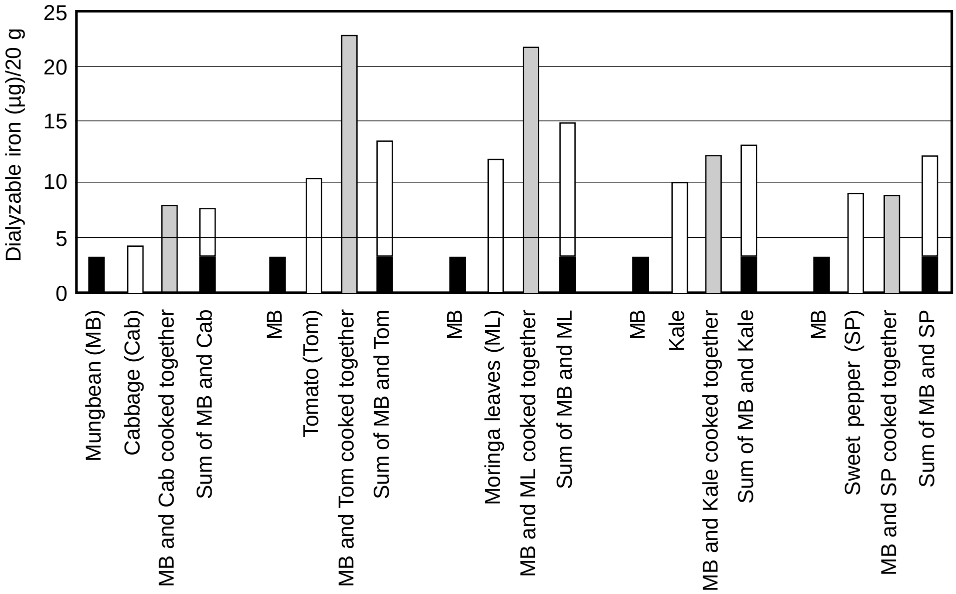


Figure 1. Effect of selected vegetables, cooked separately and together, on in vitro iron bioavailability of mungbean

Source: AVRDC, 2000

To further apply these laboratory findings for practical purposes, studies were carried out to develop culturally acceptable recipes with high available iron. Principles applied to develop these recipes were: 1) selecting vegetables which highly enhance iron bioavailability; 2) a proper ratio between iron source ingredient (mungbean) and selected vegetables is maintained to maximize the enhancing effect; 3) these two ingredients are cooked together before the cells are destructed; 4) other ingredients, such as spices, should be tested on their effect on iron bioavailability; and 5) certain ingredients, such as sugar and citric acids, are encouraged due to their positive effect on iron bioavailability. A recipe book was published based on these principles and the iron bioavailability of these dishes was estimated (Amirthaveni and Yang, 1998). Dishes selected and modified based on availability and prices of ingredients at the local markets were identified and used for the feeding trials. The results are presented in this report.

There are several methods to estimate the bioavailability of iron in food items. The in vitro method, which estimates dialyzable iron after a simulated in vitro digestion system, is less costly and more practical for a survey of various vegetables. The reliability of this in vitro method depends on the nature of enhancing or inhibitory effects and often requires confirmation by in vivo method. The enhancing effect by cooking has not yet been confirmed by in vivo method. A long-term feeding trial as reported in this publication reconfirms the enhancing effect of cooking and provides a foundation for future studies.

1.3 Organization of report

This report documents the findings from a feeding trial with schoolchildren based on supplementation with mungbean dishes in southern India. The next chapter will present an overview on the status of mungbean research in South Asia; this is followed by a chapter on consumption and production trends in mungbean, focusing on India. Chapter 4 describes the methodologies and design of the feeding trial, and Chapter 5 presents an overview on some socio-economic aspects of the study. In Chapter 6, the outcome of an econometric analysis regarding the impact of supplementation on health and performance measures is presented. The report concludes with a discussion of the results and their policy implications.

2 Current status of mungbean research

Due to its heat tolerance, mungbean is cultivated either as a summer or early kharif crop. Yield is unstable both over locations and seasons due to the susceptibility of mungbean cultivars to environmental stresses, diseases, and insect pests. As a result, mungbeans are often grown in marginal lands with minimal inputs (Shanmugasundaram and Kim, 1996). The average yield of mungbean in South Asia is only around 0.4 t/ha.

Major disease problems are mungbean yellow mosaic virus (MYMV), cercospora leaf spot (CLS), powdery mildew (PM), and root rot. Other major constraints are pre-harvest germination of seeds and weather damage due to excess moisture, and post-harvest damage by bruchid weevil (Shanmugasundaram, 1998). A socio-economic survey of farmers conducted in 1999 in strategic locations in India showed that diseases, weeds, insect pests, and environmental factors, in that order, were responsible for yield losses. The survey confirmed that MYMV, PM, CLS, and root rot diseases were priority constraints. Among insect pests, the survey identified pod borers, aphids, and thrips as most important. Drought in the far South and flooding in the central and northern parts of India were considered as serious problems for production of mungbeans (Sekar and Badal, 2001). The non-uniform maturity of older varieties is also a problem since it increases labor demands for harvesting.

Since mungbean is only a minor crop, relatively little attention has been given to mungbean crop improvement compared to cereals and major pulses such as chickpea and pigeon pea. Nevertheless, India, Bangladesh, Pakistan, and Sri Lanka have conducted research to improve the yield and yield stability through incorporation of disease resistance and adaptation in mungbean.

India has 22 research centers throughout the country carrying out mungbean varietal development work under the All India Coordinated Pulse Improvement Program. India has made a concerted effort to combat MYMV and other diseases (Tickoo and Satyanarayana, 1998). By 1980, India released more than 40 cultivars, followed by 26 more in the 1980s and 10 more since 1990 (Shanmugasundaram, 1988; Shanmugasundaram, 1998). Unfortunately, many of the newer cultivars' resistance to MYMV is unstable and short-lived.

Indian farmers did not adopt the new cultivars due to inadequate promotion of the cultivars and lack of available seed (Tickoo and Satyanarayana, 1998). Cultivars developed in the early 1970s (Kopergaon, Jalgaon 781, and Pusa Baishaki) remain popular, despite the fact they are low yielding and susceptible to MYMV. Sekar and Badal (2001) found that the farmer's realized yield of mungbean in India is only 0.29 t/ha against the potential yield of 1.15 t/ha. This yield gap was attributed to socio-economic constraints such as lack of credit, low levels of inputs, and inadequate knowledge of farmers. Recent studies in Punjab and Tamil Nadu show that the farmers are anxious to adopt the improved cultivars once they are convinced that the new cultivars are better than what they currently grow. Other studies show that progressive farmers and those who have irrigation will rapidly adopt the improved cultivars and provide necessary inputs to reap the higher yield potential.

Similarly in Bangladesh a survey conducted in 1998 in two different districts indicated that in areas where irrigation is available the farmers readily adopt the improved cultivars and provide inputs for their crop. However, in areas where the crop is rainfed, and as a result the risk is higher, farmers are reluctant to use improved varieties and do not provide inputs.

The non-availability of seed of improved cultivars remains a major problem in India and Bangladesh. There is a critical need for efficient production and distribution of quality seeds of improved cultivars after their formal release to the farmers (Abedin et al., 1999; Sekar and Badal, 2001). In response, an aggressive campaign has been undertaken both in India and Bangladesh to address this problem.

In Pakistan, mungbean varietal improvement is conducted at the National Agricultural Research Center (NARC) in Islamabad and at the Nuclear Institute for Agriculture and Biology (NIAB) in Faisalabad. Single plant selections of gamma ray-induced, MYMV-resistant mutants in 1977 laid the foundation for a shuttle-breeding program between NIAB and AVRDC. As a result, NM 92, a MYMV-resistant cultivar, was released in 1992 and officially approved in 1996 for farmers. The farmers quickly adopted NM 92 with a peak adoption rate of 51% since the cultivar gave 55% higher yields than local cultivars (Ali et al., 1997).

Since MYMV is not present in Taiwan or Southeast Asia, AVRDC did not conduct any research for the development of cultivars for South Asia until the mid 1980s. But after the discovery of the MYMV-resistant mutant in NIAB and the subsequent introduction of a shuttle breeding program, AVRDC has been able to achieve several remarkable breeding results. A number of breeding lines were selected with early maturity (65–70 days), shiny seeds of large size (5–7 g/100 seeds), uniform maturity (requiring only one or two harvests), high yield (up to 2 t/ha), and resistance/tolerance to MYMV (AVRDC, 2002).

Funded through the Department for International Development (DFID), the South Asian Vegetable Network (SAVERNET) conducted research for three years in six South Asian countries, namely Bangladesh, Bhutan, India, Nepal, Pakistan, and Sri Lanka. After two years of testing, cultivars were released in India (Pusa Vishal from the Indian Agricultural Research Institute and SML668 from Punjab Agricultural University) and in Bangladesh (BARI MUNG 5 from Bangladesh Agricultural Research Institute as well as BU1 and BU2 from Bangabandhu Sheik Mujibur Rahman Agricultural University) (Shanmugasundaram, 2002). The seeds of these new cultivars are currently being multiplied and distributed to farmers in the Indo-Gangetic Plains of South Asia. These cultivars are expected to occupy about 1 million ha in the next three years and will substantially increase the production of mungbean in the region.

3 Mungbean consumption and production in India

3.1 Mungbean consumption

Mungbean and other pulses are important sources of protein on the South Asian continent. Among all pulses, mungbean ranks third after chickpea and pigeon pea. Data from the 1995 National Sample Survey Organization (NSSO) consumption survey showed that 40% of all households had consumed mungbeans in the 30 days prior to the interview. On average, households had consumed 110 g per month, varying from 65 g to 180 g, depending on the income level, and spent between 12.7 and 15.1% of all their expenditures on pulses for mungbeans (Table 1).

Table 1. Share of mungbeans in overall consumption of pulses, India

Income group	Share of mungbeans among overall pulses consumption (%)	Annual per capita consumption (kg)	Households with positive consumption (%)
Lowest quintile	12.7	0.8	29.2
2	12.8	1.0	35.2
3	13.7	1.3	40.3
4	14.6	1.6	45.5
Highest quintile	15.1	2.1	51.7

Source: Weinberger, 2002b

Both the income and the own-price elasticity of mungbeans are relatively high. Based on a single-equation double-log demand function they were estimated at 0.649 and –1.342, respectively (Table 2). This indicates that mungbean consumption will react very strongly to both income and price changes. The price elasticity of mungbean on other pulses is similarly high (however not significant for pigeon peas). This indicates that there is a strong substitution effect: price changes for these other pulses will strongly influence total mungbean consumption. Results from Bangladesh show that mungbean consumption of farmers in irrigated areas is higher than its average consumption at the national level. Such results imply that expanding mungbean cultivation will lead to an increase in per capita consumption (Abedin et al., 1999).

3.2 Mungbean production trends

On a global level, specific data for mungbeans are not available; however among pulses, the data for dry beans (including *Phaseolus* and *Vigna* spp.) account for one of the largest groups (FAOSTAT, 2002). For the South Asia region as a whole, the production of dry beans has been relatively stagnant over the past 20 years. The average annual growth rate of total production has been –0.4%, while yields have increased slightly at an average of 0.6% per annum between 1980 and 2001.

Table 2. Expenditure and price elasticities for mungbeans in India

	Coefficient[1]	T	Significance
Per capita expenditure	0.649	21.940	0.000
Mungbean price	-1.342	-9.751	0.000
Pigeon pea price	0.179	0.988	0.323
Lentil price	0.599	3.244	0.001
Other pulses price	0.984	7.356	0.000
Constant	-9.386	-7.757	0.000
F-value	461.878		0.000
Adjusted R^2	0.698		

Dependent variable: log per capita quantity

The estimation is based on the consumption data of the rural population, and is specified as $\ln q_i = \alpha + \varepsilon_i \ln p_i + \text{Ó}\delta_j \ln p_j + \eta_i \ln Y$, where q_i is the quantity of mungbean purchased per capita, p_i and p_j are prices of mungbeans and close substitutes (pigeon peas, lentils and ‘other pulses’), and Y is total expenditure per capita. η_i and ε_i give the expenditure and own-price elasticities, respectively.

Source: NSSO, 1995

Production levels and yields vary greatly across countries (Table 3). India is the largest producer of dry beans, but harvests the lowest yields. Yields are highest in Bangladesh and Nepal. Only in Nepal and Pakistan has the total production of dry beans increased over the past 20 years. Outside of South Asia in Myanmar, both the total area under dry bean production as well as total production has increased by an average of 9%, and it is well known that this is due to the upsurge in mungbean production beginning in the early 1990s. In Myanmar, the yield of mungbean increased from 307 kg/ha in 1980–1981 to 720 kg/ha in 1996–1997. Mungbean area increased from 41,000 ha in 1980–1981 to nearly 1 million ha in 1999–2000 (Bahl, 1999).

Figure 2 charts the share of mungbean area among all pulses for the last year that data is available. The share differs from 13% in both India and Pakistan up to

Table 3. Area and yield (2001) and average annual growth rate of dry beans in South Asia and Myanmar (1980–2001)

			Annual growth rates		
	Area (1000 ha)	Yield (kg/ha)	Area (%)	Yield (%)	Production (%)
South Asia	7 469	371.2	-1.0	0.6	-0.4
Bangladesh	84	680.4	-2.4	0.4	-2.0
India	7 100	362.0	-1.1	0.6	-0.5
Nepal	39	693.6	3.1	0.6	3.7
Pakistan	219	476.7	2.4	-0.4	2.0
Sri Lanka	27	512.2	-1.1	-2.0	-3.1
Myanmar	1 850	793.3	9.1	-0.1	9.0

Source: FAOSTAT, 2002

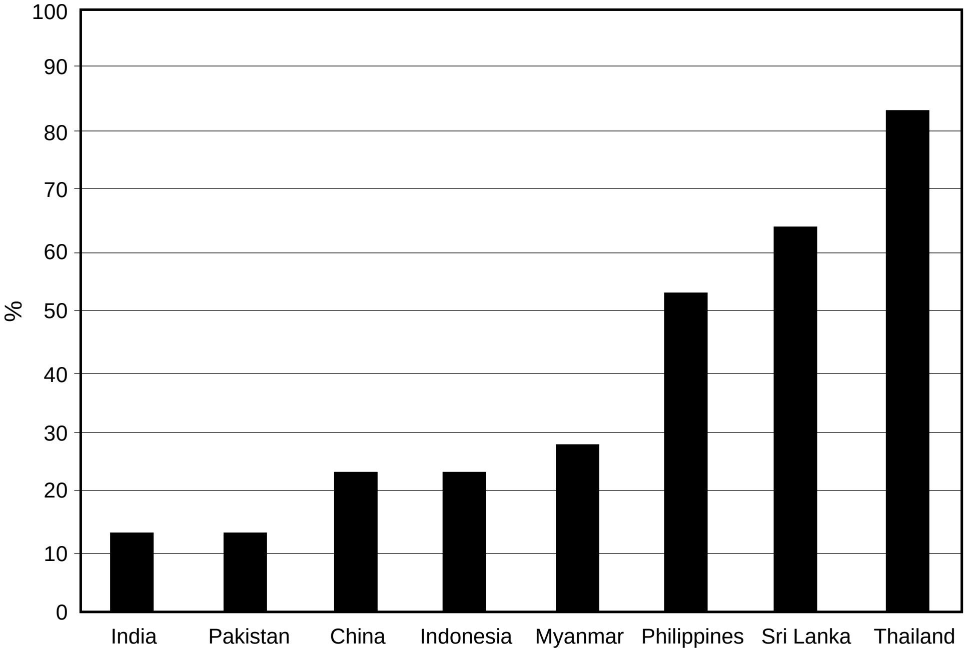


Figure 2. Share of mungbean area among all pulses for selected Asian countries

Sources: For India (1998) - Sekar and Badal (2001); for Pakistan (1998) - Economic Advisor's Wing, Finance Division; for China (2000) - Zhang et al. (2002); for Indonesia (2000) - Indonesian Ministry of Agriculture; for Myanmar (2000) - Myanmar Agricultural Statistical Office; for the Philippines (1999) - Bureau of Agricultural Statistics; for Sri Lanka (1993) - Department of Agriculture; for Thailand (1998) - Office of Agricultural Economics. Data for pulses for respective year were obtained from FAOSTAT (2002).

83% in Thailand. Mungbeans are an important pulse crop in the Philippines, Sri Lanka, and Thailand. The relatively small share in overall pulse production for Pakistan and India suggests there may be room for improvement.

A very diverse picture emerges when looking at the mungbean production in India (Table 4). Both the total area and yield levels exhibited negative growth rates from 1991 through 1998. Orissa was the leading mungbean producing state in 1991, but overall area and production there declined rapidly, apparently because the crop transformed from a high-input crop into a low-input crop for marginal areas there. In 1998, Rajasthan, Maharashtra, and Andhra Pradesh were the main mungbean producing states, together providing for 57% of the total area under production in India. The highest yields in 1998 were achieved in Punjab, Gujarat, and Bihar; it is likely that farmers in these states applied inputs since rains were favorable for mungbean production that year. However, whenever rainfall is erratic, farmers in states like Bihar will discontinue applying inputs and yields will go down. Such trends contribute to fluctuating yields in different years in most states.

AVRDC hopes to extend mungbean production throughout the Indo-Gangetic Plains. Currently, the total area in the plains remaining fallow after the wheat harvest and before planting rice in the wheat-rice cropping system is 12 million ha. The new cultivars mature in only 60–65 days when planted after the wheat harvest in April/May. Therefore they can be grown and harvested before rice is planted in mid June/July.

These new cultivars are resistant to MYMV, which is a serious disease during that season. Since the cultivars have synchronized maturity, they can be harvested mechanically, thus saving time so that the subsequent rice crop can be planted on time. Since the crop can be harvested mechanically, competition for labor with the following rice crop does not arise. The yield potential of the improved cultivars is about 2 t/ha, which is economically attractive to farmers. With the above qualifications, mungbean fits very well in the fallow period between wheat and rice in the Indo-Gangetic Plains of India. Assuming that the cultivars can successfully be promoted, both area and production will increase.

At this time, India is not able to meet its demand for pulses and has been a net importer of pulses since the 1980s. Between 1980 and 1998, net imports of pulses rose at an annual average rate of 9.2%, while the per capita availability of pulses rose by only 2.5% (Government of India, 2001). These figures underscore the declining domestic production of pulses.

However for the future, if India's GNP per capita continues to grow at an annual rate of 5%, and the population at 1.3% (UNDP, 2002), total demand for mungbean is projected to increase at an average annual rate of 4.6%. Even if income growth rates were lower at 4.0 or 3.0%, this would still translate into a total demand increase for mungbean of 3.9 or 3.2% per annum, respectively. Consumption of mungbean is expected to rise in both low as well as high income groups (Grover et al., 2003).

Table 4. Mungbean production figures for India (1998) and annual average growth rates in Indian states (1991–1998)

			Annual average growth rate		
State	Area (1000 ha)	Yield (kg/ha)	Area (%)	Production (%)	Yield (%)
Andhra Pradesh	436	281	-1.7	-1.5	0.2
Bihar	189	560	-2.5	-3.1	-0.6
Gujarat	179	567	2.8	7.3	4.6
Karnataka	248	187	-3.0	-14.4	-11.4
Madhya Pradesh	122	337	-3.8	-1.6	2.2
Maharashtra	625	313	-2.7	-2.2	0.5
Orissa	250	208	-13.9	-25.7	-11.8
Punjab	49	642	0.8	0.1	-0.9
Rajasthan	631	260	8.3	11.7	3.4
Tamil Nadu	108	408	-4.9	-5.0	-0.1
Uttar Pradesh	113	374	2.7	3.7	1.0
All India	2989	323	-2.1	-4.2	-2.1

Source: Government of India, 1991–1998

4 Set-up of feeding trial

4.1 Enhanced iron bioavailability from mungbeans

Mungbean is one of the most important legumes in India. It is easily available at all seasons and used by all income groups. Mungbean is used in different forms such as whole mungbean, mungbean dhal, sprouted mungbean, and dehulled mungbean.

In addition to its value as a protein-rich food, mungbean also has a relatively high iron content. This is especially true for new varieties such as PUSABOLD-1 (Pusa Vishal), which contains 6 mg of iron per 100 g raw seed (Vijayalakshmi et al., 2001) compared to 3.3 or 3.5 mg in the traditional varieties (Gopalan et al., 2000). Table 5 shows the relative cost of nutrients (protein and iron) in mungbean compared to other protein-rich foods. As the table shows, mungbean provides a relatively low cost source of iron. The average price of one unit (mg) of iron in mungbean is 0.53 Indian Rupees (INR) as compared to 14.03 INR in fresh fish, for example. Since mungbean contains neither inhibitors nor enhancers that influence iron bioavailability, they provide a useful staple food for food-to-food fortification (AVRDC, 2000).

Table 5. Average price for one unit of protein and iron from selected food items (INR)

Food item	Mean price/ kg	Mean price/ g protein	Mean price/ mg iron
Meat (average quality)	104.0	0.56	11.72
Fresh fish (average quality)	42.1	0.28	14.03
Mungbean	25.5	0.11	0.53
Pigeon pea	26.0	0.34	1.73
Urd bean	24.9	0.10	0.66

Source: Based on survey conducted by Avinashilingam Institute in cooperation with AVRDC (1999/2000)

The primarily plant-based diets found in developing countries are considered to have a low iron bioavailability because of their almost exclusively nonheme iron content. This is usually combined with reduced amounts of dietary enhancers for nonheme iron absorption and large amounts of dietary inhibitors found in staples such as beans, grams, cereals, beverages, and spices. The absorption of iron may be enhanced by: 1) combining vegetables (including mungbean) with foods rich in ascorbic acid; 2) avoiding consumption of beverages rich in polyphenols and in calcium; 3) consuming adequate amounts of vitamin A, riboflavin, folate, and vitamin B_{12}; and 4) cooking in iron pots (Sathya et al., 2002).

Iron availability from mungbean recipes can be determined by using the in vitro technique, representing that fraction of the dietary iron that is potentially available for absorption. The in vitro method, a recent advance, has a higher correlation than the in vivo method, is cost effective, and provides a valid estimate of available iron (Sathya et al., 2002).

One way of enhancing the bioavailability of certain micronutrients is to combine foods that, when eaten together, increase the bioavailability of these micronutrients. This strategy is called food-to-food fortification. A well-known example of this is the effect that ascorbic acid has on nonheme iron from plant sources. Ascorbic acid promotes nonheme iron absorption by reducing ferric iron to the ferrous state, which is more soluble with pH present in the duodenum and small intestine (AVRDC, 1999; Vijayalakshmi et al., 2001). Also, vitamin A and β-carotene prevent the inhibitory effect of phytates on iron absorption and thus improve iron absorption (García-Casal et al., 1997). Thus, adding vegetables such as cabbage, onions, and carrots to staple dishes can increase the absorption rates of iron in these dishes. Former research at AVRDC had focused on low-cost, easy-to-prepare dishes with high in vitro iron bioavailability based on mungbean (AVRDC, 1998; AVRDC, 2000; Amirthaveni and Yang, 1998).

4.2 Standardization of recipes

Using PUSABOLD-1 (Pusa Vishal) mungbean, recipes were standardized and estimated for in vitro iron bioavailability. To enhance iron bioavailability, different ingredients rich in ascorbic acid and vitamin A were added to mungbean recipes and then standardized.

From the surveys conducted, seven commonly used and culturally accepted recipes were selected for standardization. Each recipe was prepared using 50 g of mungbean with three variations and given to a panel of five members for tasting. The recipes were judged for their color, texture, appearance, doneness, and taste using a seven point Hedonic scale of rating (Srilakshmi, 2002). Scores were provided for each criterion. The recipes with the highest acceptability score obtained through the evaluation of the product during three consecutive evaluations were selected as the standard recipe. Thus seven recipes, namely mungbean sundal, mungbean masiyal, mungbean pesarattu, mungbean-yam kootu, mungbean-snake gourd kootu, mungbean-tomato adai, and mungbean dosai, were identified and standardized.

Vijayalakshmi and Amirthaveni (1998, 1999a) and Devadas (2001) have reported that iron absorption and bioavailability from the diet can be enhanced if they are consumed with plenty of vitamin C-rich foods such as tomato, cabbage, cauliflower, coriander, and lime juice. Using the above seven as the basic recipes, different vegetables were added and nine recipes, namely mungbean-cauliflower kootu, mungbean-cabbage kootu, mungbean-coriander leaves kootu, mungbean sundal with carrot, mungbean-tomato masiyal, mungbean sundal with raw tomato, sprouted mungbean salad, mungbean-drumstick leaves kootu, and mungbean-cabbage-coriander leaves kootu, were developed and standardized. The percentage in vitro iron bioavailability for the seven traditionally prepared and nine bioavailability-enhanced recipes are shown in Table 6.

Table 6. In vitro iron bioavailability of standardized mungbean recipes

Recipes[1]	In vitro iron bioavailability (%)
Traditionally prepared recipes	
Mungbean sundal	7.69
Mungbean masiyal	5.75
Mungbean pesarattu	8.20
Mungbean-yam kootu	8.39
Mungbean-snake gourd kootu	2.96
Mungbean-tomato adai	4.98
Mungbean dosai	7.56
Iron bioavailability-enhanced recipes	
Mungbean-cauliflower kootu	13.25
Mungbean-cabbage kootu	13.09
Mungbean-coriander leaves kootu	12.53
Mungbean sundal with carrot	12.24
Mungbean-tomato masiyal	12.39
Mungbean sundal with raw tomato	8.73
Sprouted mungbean salad	8.17
Mungbean-drumstick leaves kootu	6.69
Mungbean-cabbage-coriander leaves kootu	6.16

[1] Sundal - Boiled/pressure cooked mungbean, seasoned with spices and coconut scrapings
Masiyal - mungbean cooked and mashed
Pesarattu - pancake, using soaked and ground mungbean and rice
Kootu - curry with mungbean, designated vegetable, and coconut scrapings
Tomato adai- pancake, using soaked and ground mungbean with tomato
Dosai - pancake, using soaked and grounded mungbean
Sprouted mungbean salad - vegetables with sprouted mungbean

Sources: Vijayalakshmi et al. (2001) and Sathya et al. (2002)

From the above recipes, mungbean sundal and mungbean masiyal were selected from traditionally prepared recipes since they are the most common preparations and because low-cost vegetables such as tomato are commonly available throughout the year. From the iron bioavailability-enhanced recipes, mungbean-cabbage kootu, mungbean-tomato masiyal, and mungbean sundal with carrot were selected for the feeding trials.

Table 7 shows the nutrient content of one ration of each of the different mungbean preparations, which were standardized in respect to iron, energy, and protein contents. The contents of these three nutrients are relatively equal in each of the five different preparations. The group receiving traditional mungbean preparations (TR) received mungbean sundal and mungbean masiyal on an alternating basis, while the group receiving the ascorbic acid-enhanced recipe (IR1) received the alternating traditional recipes with cabbage and tomato added. A third group received an iron bioavailability-enhanced recipe with high β-carotene content, namely mungbean sundal with carrot (IR2).

Table 7. Nutrient content of one portion of mungbean preparation

Preparation	Energy (Kcal)	Protein (g)	Iron (mg)	Retinol (µg)	Asc. acid (mg)
Traditional (TR)					
Mungbean sundal	284.7	13.1	2.8	14.4	8.4
Mungbean masiyal	280.2	13.2	2.8	15.3	7.3
Iron bioavail.-enhanced (IR1)					
Mungbean-cabbage kootu	285.1	13.2	2.8	25.9	51.9
Mungbean-tomato masiyal	283.0	13.0	2.8	57.2	18.3
β–carotene improved (IR2)					
Mungbean sundal with carrot	283.7	12.8	2.8	141.7	8.5

Source: Vijayalakshmi et al. (2001)

Increasing the iron bioavailability of recipes was achieved while keeping the cost of food preparation comparable to traditional mungbean recipes. Table 8 shows that the costs of the five supplements are relatively equal, around 15 INR per ration. The in vitro iron bioavailabilities of the enhanced recipes (IR1 and IR2) are significantly higher at 12.2–13.1% compared to 5.8–7.7% for traditional recipes.

Table 8. Cost of mungbean dishes and in vitro iron bioavailability

Dish	Cost per portion (INR)	Iron bioavailability (%)
Mungbean sundal	14.9	7.7
Mungbean masiyal	14.7	5.8
Mungbean-cabbage kootu	14.7	13.1
Mungbean-tomato masiyal	15.9	12.4
Mungbean sundal with carrot	14.5	12.2

Sources: Weinberger (2002b) and Vijayalakshmi et al. (2001)

4.3 Survey design

Children in the age group of 10–12 years were selected from a total of two government higher secondary schools of two villages in the Periyanaickenpalayam block in Coimbatore city, located in Tamil Nadu, India. Children from one village served as the experimental group and the children from the second village served as control.

The feeding trial was conducted from October 1999 through October 2000. In total, 225 school children participated in the study (113 boys and 112 girls). Of these, one group of 50 children received a daily supplementation of a traditional mungbean preparation (TR), two groups of 50 children each received a daily supplementation of bioavailability-enhanced mungbean preparations (IR1 and IR2), and the control group of 75 children received no supplementation (Table 9). Height and weight measurements were taken quarterly for every group; hemoglobin levels were taken before and after supplementation based on the finger prick method and analyzed using the cyanmethoglobin method (Gowenlock, 1988). For a subsample of 10% of the children, the following biochemical parameters were additionally analyzed:

- the estimation of serum iron using the method of Teitz (1976)
- the estimation of serum TIBC using the method of Ramsay (1958)
- the estimation of serum ferritin using the enzyme-immuno assay method by Teitz (1976)

Performance in sports activities and stamina levels were assessed before and after the supplementation period (Vijayalakshmi et al., 2001).

Table 9. Composition of feeding groups

	TR				IR1				IR2				Control	
Sex	Boys		Girls		Boys		Girls		Boys		Girls		Boys	Girls
Initial age	10	11	10	11	10	11	10	11	10	11	10	11	11	11
Number	6	19	5	20	8	17	4	21	9	16	5	20	38	37
Total	50				50				50				75	

Source: Based on survey conducted by Avinashilingam Institute in cooperation with AVRDC (1999/2000)

5 Socio-economic background and consumption patterns

5.1 Socio-economic background of families

Table 10 shows that the families were essentially nuclear in nature and 90.7% of the sample had a family size of between four to six members. Slightly more than one-third of the family heads (35.6%) were daily wage earners. Among the sample, 20.8% of the parents were working in the brick manufacturing units in the local areas, 10.6%

Table 10. Socio-economic background of families in the survey

Characteristic	Number	%
Type of family		
Nuclear	203	90.2
Joint	22	9.8
Total	225	100.0
Family size		
0–3	13	5.7
4–6	204	90.7
7+	8	3.6
Total	225	100.0
Educational status of head		
Illiterate	96	42.6
Literate	23	10.2
Up to elementary	47	20.8
Up to high school	51	22.6
Up to higher secondary	4	1.7
Degree	1	0.4
Certificate course	3	1.3
Total	225	100.0
Occupational status of the head		
Daily wage earner	80	35.6
Brick manufacturing work	47	20.8
Agriculture	24	10.6
Government employee	5	2.2
Others	69	30.7
Total	225	100.0
Monthly income		
Low (INR1125–2650)	119	52.9
Middle (INR 2650–4450)	90	40.0
High (INR 4451+)	16	7.1
Total	225	100.0

Source: Based on survey conducted by Avinashilingam Institute in cooperation with AVRDC (1999/2000)

48INR = 1 USD

were agricultural laborers, and only 2.2% were government employees. All others (30.7%) were doing petty jobs. The educational status of the heads of the families was very poor. Only 0.4% were degree holders, 20.8% had studied up to primary school, 22.6% up to high school level, 1.7% up to higher secondary level, and the remaining 42.6% were illiterate. Based on the Indian standards of living, 52.9% were in the low income group, 40% were in the middle income group, and only 7.1% were in the high income group.

5.2 Consumption patterns in families

The majority of the Indian population subsists on suboptimal and imbalanced diets. Poverty remains a major cause of hunger and malnutrition and this situation is further aggravated by the rapid growth of population, unhealthy environment, and lack of education. More than half of the children in India are unable to grow to their full physical and mental potential owing to malnutrition. Fifty percent of the adult population in India and 53.4% of the children are reported to have a Body Mass Index (BMI, weight divided by squared size) below normal (NIN, 1998). A survey conducted by National Nutrition Monitoring Bureau (NNMB, 1998) indicates that the daily intake of most foods in Indian households, except for cereals and millets, is much below the recommended dietary allowances (RDA).

Overall, the scenario of the net per capita availability of fruits, pulses, vegetables, milk, and egg is rather grim. Pulse intake, which was 60.7 g in 1951, has come down to 36 g in 1999/2000. In India, despite being one of the leading nations in fruit and vegetable growing, the per capita availability of these commodities is only 46 g and 140 g per day, respectively. According to Gopalan et al. (2000), a balanced diet should contain nearly 100 g of fruit and 300 g of vegetables (including tubers) per day. The consumption of green leafy vegetables, which are rich sources of micronutrients such as β-carotene, folate, calcium, riboflavin, and iron, is woefully inadequate (Kaul, 1998).

There are several additional distressing trends in Indian diets. Per capita daily energy intake was 2296 calories during the year 1975, rising to 2409 during 1981, and then gradually declining to 2172 in 1995 (2425 calories is the recommended daily amount). The daily intake of protein was 64 g during 1975 but only 56 g in 1995 (60 g is recommended). The daily intake of iron dropped from 32 mg in 1975 to 26 mg during 1995 (28 mg is recommended). The daily intake of vitamin A has slightly rose from 263 µg in 1975 to 288 µg in 1995, but this is still well below the recommended level of 600 µg. Thus the picture of nutrient intake is very grim (NNMB, 1998).

Turning to consumption of mungbean, Figure 3 shows the popularity of this pulse crop in South India. In the survey sites, all sampled families had consumed mungbean and red gram (*Cajanus cajan*) in the month preceding the survey. In contrast, approximately two-thirds of all families had consumed horse gram (*Dolichos biflorus*) and bengal gram (*Cicer arietinum*), and one-third or less of all families had consumed other available pulses.

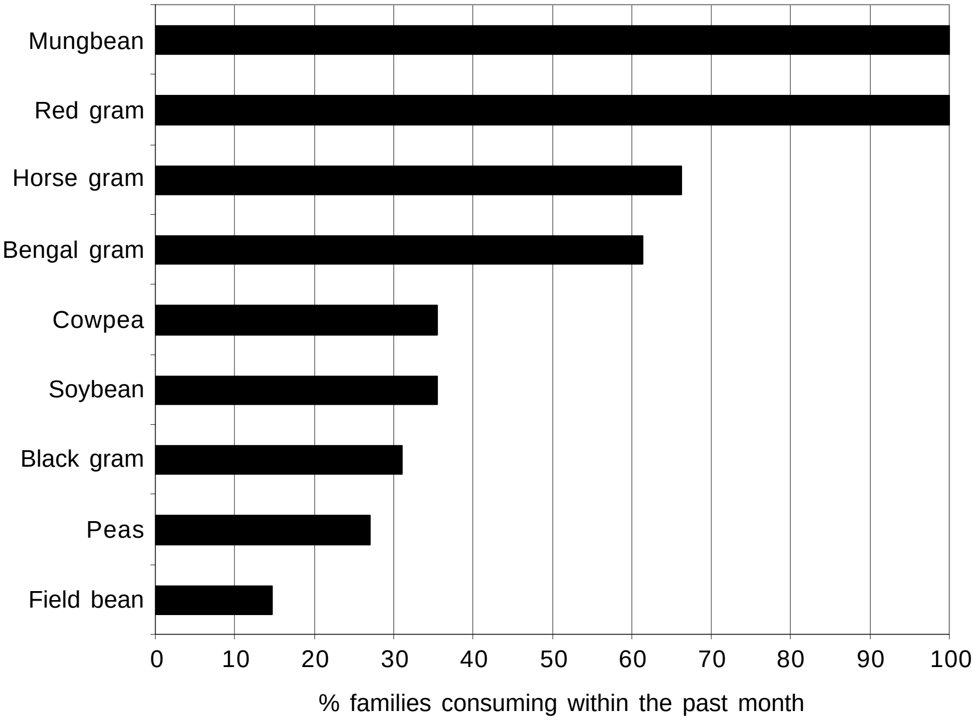


Figure 3. Preference in consumption for different pulses

6 Effects of increased iron bioavailability on health

6.1 Initial health situation of children

Table 11 shows initial anthropometric data for boys and girls participating in the feeding trial. Girls on average were somewhat larger and heavier than boys, and in terms of the Body Mass Index (BMI), girls were healthier than boys, but both girls and boys scored less than the standard BMI for Indian children of that age (Agrawal et al., 1987).

Table 11. Initial anthropometric data

Sex		Initial height (cm)	Initial weight (kg)	Initial BMI	Standard BMI[1]
Boys	Mean	134.6	26.5	14.6	17.3
	SD	5.3	3.4	1.5	
Girls	Mean	136.8	28.8	15.4	17.7
	SD	5.6	4.1	2.1	
Total	Mean	135.7	27.6	15.0	
	SD	5.5	3.9	1.9	

[1] For 11-year old (Agrawal et al., 1987)

Source: Based on survey conducted by Avinashilingam Institute in cooperation with AVRDC (1999/2000), N = 225 school children

The initial analysis of selected symptoms for iron deficiency (weakness, paleness of eye, and fatigue) showed that girls were more severely affected than boys. About half of the girls complained about weakness, and every fifth girl was easily fatigued (Table 12). However, fewer girls than boys were affected by other vitamin A deficiency symptoms, namely delayed dark adoption and dry/rough skin.

Turning from clinical symptoms to the biochemical analysis, the initial low values indicate that anemia was based on which participants in the feeding trial were selected.

Table 12. Initial clinical deficiency symptoms

	Boys		Girls		Total	
	%	SD	%	SD	%	SD
Weakness	21.2	41.1	50.9	50.2	36.0	48.1
Easily fatigued	5.3	22.5	20.5	40.6	12.9	33.6
Delayed dark adoption	12.4	33.1	9.8	29.9	11.1	31.5
Dry and rough skin	31.9	46.8	20.5	40.6	26.2	44.1

Source: Based on survey conducted by Avinashilingam Institute in cooperation with AVRDC (1999/2000), N = 225 school children

Table 13 shows the initial anemia prevalence. For this age group, the cut-off point for blood hemoglobin concentration that suggests anemia is 11.5 g/dl (ACC/SCN, 2000), a value that was reached by none of the participating children. Approximately one-fourth of all boys and nearly half of all girls were severely anemic, with hemoglobin levels below 7.0 g/dl.

The distribution of severe anemia between boys and girls mirrors the clinical deficiency symptoms between the two sexes. For boys, the mean initial hemoglobin level was 8.2 g/dl, for girls it was lower at 7.3 g/dl (Table 14). The maximum value achieved was 9.7 g/dl, hence anemia among all participants ranged from moderately to severely anemic. Serum ferritin, serum iron, and the total iron binding capacity (TIBC) were other indicators of body iron stores and were assessed for a subsample of 23 children. Indicators of anemia are serum iron levels below 40 µg/l, serum ferritin levels below 10 µg /l, and TIBC above 500 µg /dl in humans (UNICEF/UNU/WHO/MI, 1998). The table shows that all children participating in the feeding trial were initially anemic, by all indicators used.

Table 13. Initial anemia prevalence

	Boys		Girls		Total
Hemoglobin level (g/dl)	N	%	N	%	N
Severely anemic (<7.0)	30	26.5	50	45.0	80
Moderately anemic (7.0 – <10.0)	83	73.5	61	55.0	144
Total	113	100.0	111	100.0	224

Source: Based on survey conducted by Avinashilingam Institute in cooperation with AVRDC (1999/2000)

Table 14. Initial biochemical parameters

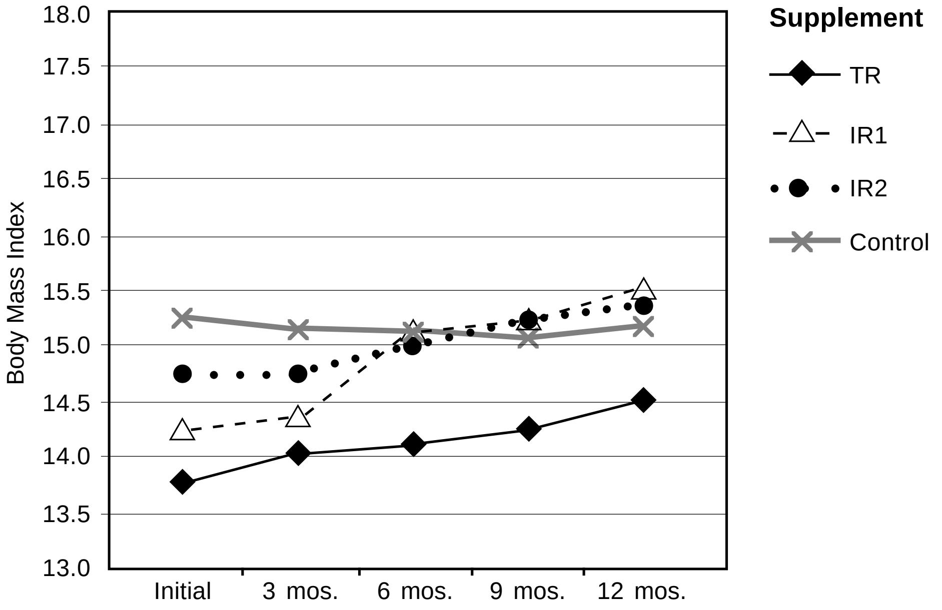
	Boys			Girls			Total		
	Mean	SD	N	Mean	SD	N	Mean	SD	N
Hemoglobin (dl/l)	8.2	1	113	7.3	0.9	111	7.8	1.1	224
Serum iron (µg/l)	25.2	2.8	12	22.5	3.1	11	23.9	3.2	23
Serum ferritin (µg/l)	3.1	0.4	12	3.2	0.4	11	3.2	0.4	23
Serum TIBC (µg/dl)	545.7	9.6	12	544.5	9.5	11	545.1	9.3	23

Source: Based on survey conducted by Avinashilingam Institute in cooperation with AVRDC (1999/2000)

6.2 Impact of supplementation on weight and height

Girls and boys were measured in weight and height every three months after initialization of the survey. Figure 4 shows how the BMI was affected by supplementation over the year. Girls had a higher initial BMI than boys and the average gain over the course of one year was more than one index point for all three treatment groups. In contrast, for boys the average gains were smaller; only boys in IR1 on average gained more than one index point in their BMI. For both sexes, the control group did not record substantial changes over the course of one year.

Boys



Girls

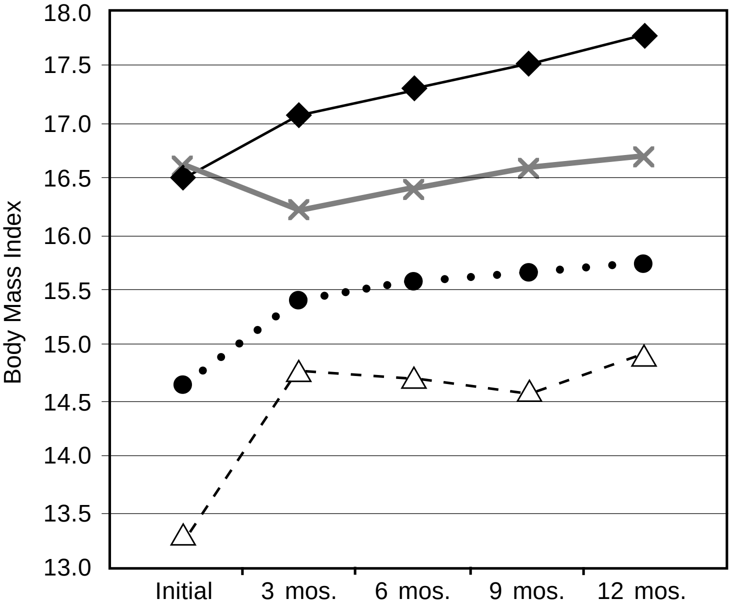


Figure 4. Impact of supplementation treatments over time on Body Mass Index of boys and girls

Source: Based on survey conducted by Avinashilingam Institute in cooperation with AVRDC (1999/2000), N = 225 school children

6.3 Impact of supplementation on blood/serum contents

Figure 5 shows how supplementation affected the prevalence of anemia among boys and girls. As reported earlier, fewer boys than girls were severely anemic before supplementation. Supplementation improved blood iron values in all groups of boys and 15% of boys receiving bioavailability-enhanced mungbean preparations improved in health status to being only mildly anemic (10–11 g/dl).

All girls remained moderately or severely anemic after supplementation. However, improvements in blood iron values were made, especially for groups that received the iron bioavailability-enhanced mungbean preparation. In the control group, the percentage of severely and moderately anemic girls did not change over the period. In general for both boys and girls, supplementation greatly improved blood iron values but could not overcome anemia.

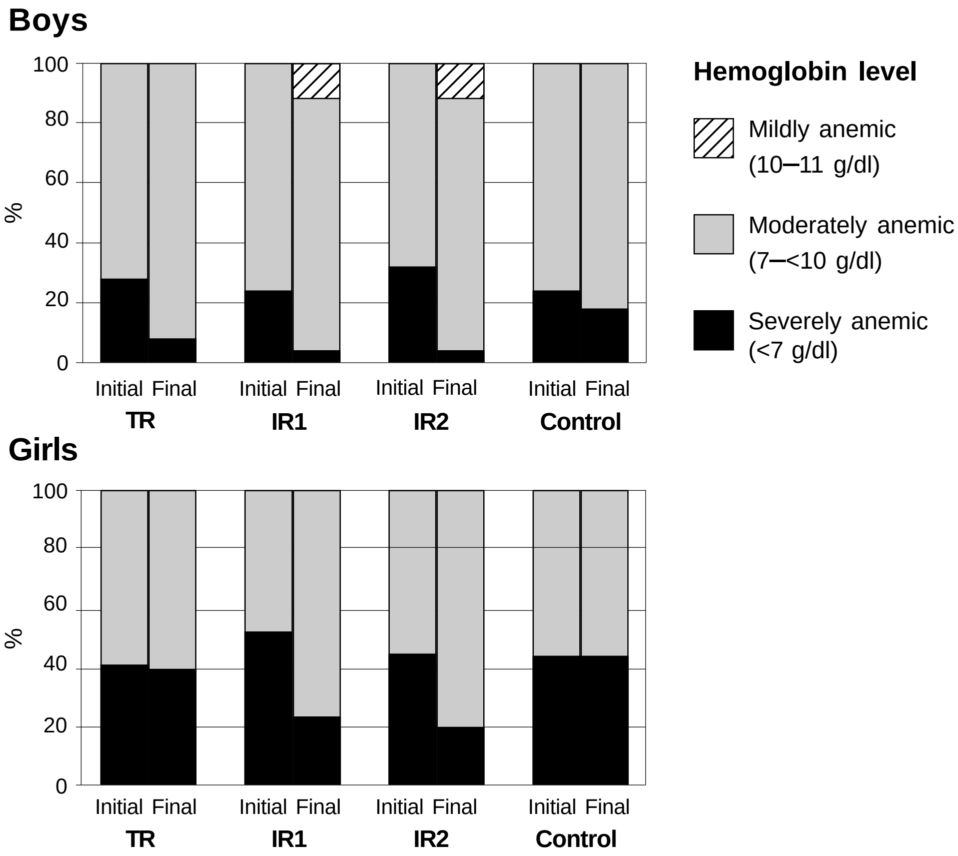


Figure 5. Anemia prevalence among boys and girls before and after supplementation

Source: Based on survey conducted by Avinashilingam Institute in cooperation with AVRDC (1999/2000), N = 225 school children

The results of a regression analysis on the effects of supplementation on blood iron content are shown in Table 15. The dependent variable is the absolute change in hemoglobin level after supplementation as compared to before supplementation. The model controls for the feeding group, the initial hemoglobin level, the initial BMI, and for sex and age of the participating child. Membership in one of the three feeding groups is a highly significant determinant variable for the change in the hemoglobin level as compared to the control group. The effect on the change in hemoglobin level was highest for children that received a daily supplementation with β-carotene-enhanced mungbean preparation. For this group, the hemoglobin level on average was 0.8 g/dl higher than for the control group, indicating an average increase of about 10% in this group. The difference was slightly less for the group IR1. Even the group that received a traditional preparation of mungbeans on average still had a 0.3 g/dl higher hemoglobin level in their blood compared to the control group.

Table 15. Effects of supplementation on hemoglobin level

Parameter	Coefficient	SD	t-value
Constant	0.371	0.249	1.490
Initial hemoglobin level (g/dl)	-0.014	0.008	-1.768
Initial BMI	1.86E-04	0.005	0.039
Supplementation			
Member of TR (yes = 1)	0.336	0.022	15.585
Member of IR1 (yes = 1)	0.771	0.023	33.068
Member of IR2 (yes = 1)	0.794	0.022	35.924
Sex (girls = 1)	-0.073	0.017	-4.323
Age	-0.023	0.022	-1.028
R^2	0.905	0.113	
F-value	305.119		

Dependent variable: Absolute change in hemoglobin level after supplementation

Source: Based on survey conducted by Avinashilingam Institute in cooperation with AVRDC (1999/2000), N = 225 school children

Concerning the other variables, girls recorded a slightly lower change in their hemoglobin level than boys (0.073 g/dl). Age and the initial BMI did not show a significant impact, and the gain seemed to be slightly lower for those with initially higher levels of hemoglobin (a 1% higher initial level resulted in a 0.26% lower gain). However, this result is only marginally significant at the 0.07% level. Thus, the regression analysis emphasizes the former result that supplementation had a significant positive effect on hemoglobin levels, and this effect was largest for children of the group that received an iron bioavailability enhanced supplementation with high β-carotene content (IR2). Yet, it also shows that gains were only in the order of 5 to 10%. To overcome iron deficiency anemia, gains would have had to be in the order of 50%. This result underlines that food-based approaches are not a valid therapeutic approach but are an effective way to increase low body iron stores.

Table 16 shows the impact of supplementation on other biochemical parameters that are indicators for body iron stores, again based on a regression analysis. This analysis was undertaken for a sub-sample of 23 children only. The results are very similar to those presented in Table 15. Again, they are highly significant. For all three dependent variables (absolute change in serum iron, serum ferritin, and TIBC after supplementation) membership in one of the three treatment groups was highly significant, and changes were largest for children that received either IR1 or IR2. For serum iron and serum ferritin, the sex of the child also has a significant impact on the outcome, as girls on average experienced a smaller change. The results of this analysis underline those gained by the former: significant changes in body iron stores can be obtained by daily consumption of nonheme iron if a high bioavailability of the iron consumed is ensured.

Table 16. Effects of supplementation on further biochemical parameters

	Serum iron (µg/l)		Serum ferritin (µg/l)		TIBC (µg/dl)	
Parameter	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value
Constant	23.91	0.37	-1.23	-0.39	136.43	0.83
Initial BMI	0.17	0.28	0.06	1.94	-0.84	-0.55
Initial Hemoglobin level (g/dl)	-2.24	-0.59	-0.07	-0.37	-11.89	-1.25
Member of TR (yes = 1)	19.29	7.01	0.62	4.67	-31.38	-4.51
Member of IR1 (yes = 1)	24.84	7.83	2.02	13.26	-56.44	-7.05
Member of IR2 (yes = 1)	27.22	6.81	2.06	10.72	-68.62	-6.80
Sex (female = 1)	-5.86	-2.74	-0.28	-2.75	-1.17	-0.22
Age	-0.41	-0.09	0.10	0.45	-1.66	-0.14
R^2	0.87		0.94		0.85	
F-value	23.75		52.81		18.98	

Dependent variable: Absolute change in serum iron, serum ferritin and serum TIBC after supplementation

Source: Based on survey conducted by Avinashilingam Institute in cooperation with AVRDC (1999/2000), N = 23 school children

6.4 Impact of supplementation on physical performance

Since iron deficiency anemia is known to influence productivity (iron helps to deliver oxygen from the lungs to the body), the examinations included an analysis of children’s stamina. Different forms of physical exercise were undertaken by boys and girls before and after the supplementation period.

All three groups that received supplementation recorded increases in their stamina as compared to the control group, and significant differences were also apparent across feeding groups (Table 17). There is no clear evidence that the groups receiving bioavailability-enhanced recipes fared better than the children that received the traditionally prepared recipe. For children that are usually deficient not only in their micronutrient intake, but in energy and protein intake as well, improvement in performance may result not only from an increase in their hemoglobin levels, but from the overall fact that more daily energy and proteins are available to them. It is therefore difficult to ascertain that differences in performance can be attributed to enhanced body iron stores alone.

Table 17. Changes in productivity parameters

Activity	Group	Mean	SD	Change (%)	Paired t-test
Sit-ups (boys)	TR	18.4 a[1]	2.2	31.3	-8.74
	IR1	17.5 a	3.2	25.9	-8.05
	IR2	16.9 a	3.6	33.5	-7.41
	Control	13.7 b	3.0	-1.1	0.28
100-m run (boys)	TR	9.8 b	0.6	12.0	-6.74
	IR1	10.3 a	0.5	19.6	-12.99
	IR2	10.2 a	0.6	16.4	-18.64
	Control	9.0 c	0.5	1.3	-1.30
Long-jump (girls)	TR	2.7 a	0.2	5.7	-9.08
	IR1	2.5 b	0.2	5.0	-5.49
	IR2	2.6 ab	0.2	5.3	-4.84
	Control	2.4 c	0.2	-1.7	1.92

[1] Different letters within each activity indicate means that are statistically different

Source: Based on survey conducted by Avinashilingam Institute in cooperation with AVRDC (1999/2000), N = 225 school children

7 Discussion of results and policy implications

This paper has presented the findings of a feeding trial based on mungbean supplementation that was conducted among schoolchildren in southern India. The feeding trial lasted one year and included 225 children. Health parameters and physical stamina of children were examined before and after supplementation for three treatment groups and one control group. One treatment group received a traditionally prepared dish with a normal in vitro iron bioavailability at around 7% while two groups received iron bioavailability-enhanced dishes at around 12%.

The results indicate that supplementation improved health parameters. Children receiving supplementation suffered from less clinical deficiency symptoms after supplementation. For biochemical parameters the improvement was significantly larger for the two groups receiving iron bioavailability-enhanced supplementation than for the group receiving a supplementation with a low iron bioavailability. In the former two groups (IR1 and IR2), hemoglobin levels increased by an average of 10%, while in the group that received the traditional preparation (TR), hemoglobin levels increased on average by 5%. However, in no case did the hemoglobin level rise over anemic levels. The results show that food-based approaches on plant-based diets do not resolve severe forms of anemia in the short term. Yet, they are a viable a long-term strategy to fight micronutrient deficiencies. As Gopalan (1998) states, “the logical and physiological approach towards combating any nutritional deficiency in a population must lie in bringing about appropriate corrections in the habitual diet of the population.”

For an assessment on the effect of supplementation on performance and overall physical stamina, the analysis does suggest that supplementation has a positive effect. It is not clear, though, whether this effect can be attributed to the higher iron bioavailability of the supplement. Overall higher availability of energy and protein may also have contributed to the increased physical well being of children, since no differences between the three treatment groups could be observed.

The analysis shows that enhancing iron bioavailability through modified preparations of local dishes are a cost-effective way of improving the iron status of population groups at risk. Dishes with a higher in vitro iron bioavailability do not incur higher costs of preparation than traditional dishes. Promoting dishes with a higher iron-bioavailability based on mungbeans appears to be a viable strategy to enhance body iron stores in regions where diets are predominantly vegetarian and the inclusion of animal products into diets is not feasible. Opportunities to promote the modification of existing preparation practices through nutrition education and local media should be used to reach a large number of households.

Changing consumption practices is only one of several components of a food-based approach to increase intake of micronutrients. Using nutrition education and mass communication technologies are additional means of reaching this goal. Other components of such a strategy include a focus on improved production technologies for vegetables. Studies have shown that diversity in consumption increases when production of vegetables increases (AVRDC, 2002; Marsh, 1998; Weinberger, 2001b).

In terms of further research it would be desirable to know more about the cost-effectiveness of such programs for improving the iron status of population groups at risk, particularly when considering the effect on productivity. Due to the large number of iron deficient persons in India, and the large and negative effects on productivity of individuals, it can be expected that food-based approaches to improve the iron status of the population will yield good results at a relatively low cost per person.

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