

# FOOD AND NUTRITION BULLETIN

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Lysine fortification of wheat flour

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Fast and reliable salt iodine measurement

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Increasing the stability of iodine in iodized salt

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Biocultural diversity in the sustainability of developing-country food systems

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on Diet, Physical Activity and Health —*Enrique R. Jacoby, guest editor*

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Promoting physical activity in the Americas

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# Lysine fortification: Past, present, and future

Peter L. Pellett and Shibani Ghosh

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## Introduction

The papers by Hussain et al. [1] and Zhao et al. [2] are further episodes in the long-running saga on whether lysine fortification in free-living, cereal-dependent populations can produce significant nutritional and health benefits. These studies were performed in Pakistan and China, in 1996–97 and 1999, respectively. Over the years, many investigations involving lysine have taken place with human subjects, but despite the care taken in experimental design, the study outcomes in free-living populations have remained equivocal, and the practice of lysine fortification of human dietaries has not been implemented other than under experimental conditions. In contrast, in developed economies, lysine fortification of cereal-based animal feeds is widespread for the purpose of producing more rapid and greater weight gain and hence improved profitability.

In this paper, we will discuss the assessment of lysine status from food balance sheet data, previous human fortification studies, lysine in animal feeds, and some thoughts for the future of lysine fortification.

## Nutritional background

Staple food availability at the national, regional, and household levels is a cornerstone of nutritional well-being. Aggregate estimates of food availability at global, regional, or country levels, while often indicative, cannot truly reflect household or individual food

consumption. Factors affecting the latter include the abilities of households to produce or procure food, which themselves are functions of income levels and distribution, food availability and wastage, and prices and consumer choices.

The majority of the deprived and undernourished population in the world subsists on diets heavily based on cereals. Such diets are likely to be low in a number of micronutrients, including the amino acid lysine. When comparisons have been made between food availability data for various countries, it has been demonstrated that as wealth (gross national product or GNP) decreases, not only is food energy availability reduced, but there are also major changes in the pattern of foods selected. In particular, there are significant decreases in the availability of animal protein foods and increases in the dependency on cereals [3–8]. Further analysis also indicates that, of the essential amino acids, lysine is the amino acid for which the largest differences occur between the diets of the rich and the poor. It was also observed that the amino acid compositions of animal, pulse, and cereal proteins are sufficiently distinctive from each other to enable food-group data to be used for simple predictions of the lysine value of diets [8]. From examination of standard tables of amino acid composition [9], it was demonstrated that the lysine content of most cereals ranges from 26 to 38 mg per gram of protein, whereas the lysine content of animal foods is much higher, ranging from 70 to 100 mg per gram of protein [6, 8]. These relationships thus permit the estimation of lysine value from considerations of the amounts of animal protein and cereal protein present.

Thus, the socioeconomic status of both households and populations strongly influences the quality of available dietary protein. The effect of wealth status on the diet is illustrated in table 1 [8]. Although these data are for 1992–93, the relationships remain relevant. An increase in socioeconomic/wealth status (signified by per capita GNP) corresponds to an increase in the availability of total food energy, total protein, and animal protein. Between those with GNPs of less than

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TABLE 1. Total population, nutrient availability, mortality rate, and life expectancy for world economic classes (data from 122 countries)

GNP (US\$/person/yr)	No. of countries	Population (millions)	Food energy (kcal/day)	Total protein (g/day)	Animal protein (%)	Cereal protein (%)	Pulse-soy protein (%)	Mortality, children < 5 yr (/1000)	Life expectancy at birth (yr)
< 500	37	2,990	2,070	51	20	53	11.4	171	52
500–2,000	41	862	2,570	65	31	50	7.0	76	64
2,000–10,000	21	548	2,913	78	45	39	5.6	39	69
> 10,000	23	806	3,335	101	61	24	2.7	9	77

GNP, Gross national product. Source: ref. 8. Data for 1992–93.

\$500 per capita and those with GNPs greater than \$10,000 per capita, food energy availability increased by some 50% and total protein availability doubled, while the percentage of animal protein increased threefold. Although not shown in table 1, lysine would be expected to increase along with the increase in animal protein. For the same comparisons (under \$500 to above \$10,000 per capita) the mortality rate among children under five years of age declined from 171 to 9 per thousand live births.

### Essential amino acid requirements and supply

Human lysine requirement remains the subject of current collaborative international research, and future agreement on the actual value is essential for the assessment, on a global basis, of those at risk for deficiency, as well as for the assessment of whether diets meet essential amino acid needs. Thus, reference standards are needed for comparison. This remains true whether values are expressed in absolute terms of milligrams per day or in quality terms of milligrams per gram of protein. The earlier 1991 requirement [10] of lysine for the adult was 58 mg per gram of protein, which translates to 2,840 mg per day for a young 65-kg adult male whose protein requirement is 49 g per day. Alternative recommendations, based on stable isotope studies, have been proposed [11], in which the lysine requirement for the adult has been reduced to 50 mg per gram of protein or 2,450 mg per day for the same young adult male.

From recent international deliberations, the value for the adult is likely to be reduced even further to 45 mg per gram of protein by the Food and Agriculture Organization/World Health Organization (FAO/WHO) expert group concerned with protein and amino acid requirements whose report is awaiting publication [12]. The new lower adult values will be used in the present assessment. In practice, however, population requirements are higher, because the needs of babies, children, and pregnant and lactating women are all greater than those of the adult male, with the requirement of the young baby being as high as 69 mg per gram of protein [12]. The requirements for the other essential amino

acids have not been changed to any significant degree, and thus lysine remains the first limiting amino acid in many world dietaries. An approximate rule of thumb is that a population average at or below the adult requirement value of 45 mg per gram of protein may be indicative that a significant proportion of the population is at risk for lysine deficiency.

Although risk assessment can only be made with accuracy by using estimates based on individual variability of intake, the best estimates of those at risk must continue to be based on population average values, such as those derived from food balance sheets. These are the only readily available data that can be used to make population-wide estimates of nutritional availability. Provided that the limitations of such procedures are recognized, useful conclusions can be drawn.

Typically, food balance sheet data for each year and for each country or region consist of 100 to 150 food items. Thus, even with computer assistance, data entry and subsequent calculations are time-consuming. It has, however, been observed [6, 8] that, in practice for countries and regions, a much smaller number of food items (some 20 to 30) provide the majority of the protein, allowing for a simplified calculation procedure. These dietary components include the major cereals, such as wheat, rice, corn, millet, and sorghum; the starchy roots cassava, sweet potato, and potato; the pulses soybean, groundnut, and common beans; and the animal food products, primarily meat, milk, fish, and eggs. The estimation of lysine value from food balance sheet data has been further simplified by Pellett [8], who developed prediction equations from multiple regression analysis. The best prediction ( $R^2 = .98$ ) involved the three groups of major protein sources:

$$\text{Lysine (mg/day)} = 86.3\text{AP} + 19.8\text{CP} + 63.6\text{PSP} + 599$$

where AP, CP, and PSP were animal, cereal and pulse (including soy) protein, respectively, in grams per day. Cereal protein (grams per day) by itself is a nonsignificant predictor of daily lysine availability. This is because in developing-country diets, although cereal protein may constitute a high proportion of the total protein, the amount of cereal protein in absolute terms (grams per day) is often similar to that in developed countries. Because of the high degree of predictability

( $R^2 = .98$ ) of dietary lysine from animal, cereal, and legume protein contents, the prediction equation above was used to calculate lysine availability (milligrams per day) from food balance sheet data. Lysine (milligrams per gram of protein) was subsequently calculated from daily lysine by dividing by total protein per day.

Some calculations showing estimated lysine values, using the procedures described above, are given in table 2 for selected FAO regional and economic groupings of countries using FAO on-line food balance sheets for 2001 [13]. A very significant difference between nutrient availabilities in developed and developing regions can be seen. Developed regions, as a group, had average availabilities of 3,285 kcal and 99.4 g of protein per day, with 56.1% of the protein being of animal origin. In contrast, the developing countries had a lower average availability of food energy of 2,675 kcal, together with 69.6 g of protein per day. Only 29.5% of this protein was of animal origin. When lysine values were estimated, only 3,454 mg per day were available, on average, in the developing countries, compared with 6,167 mg per day for the developed regions. A comparison between the North America Developed and the Sub-Saharan Africa Regions shows even more extreme differences in availabilities of 7,419 and 2,466 mg/day, respectively. In terms of milligrams per gram of protein, the values are 65.5 for North America and 44.9 for Africa. With the probable requirement value for the adult at 45 mg per gram of protein, it could thus be anticipated that a significant proportion of those in Africa might be at risk of lysine deficiency.

Further examples from selected individual countries are shown in table 3. According to the same criteria, Syria, Bangladesh, Nigeria, Egypt, Morocco, and Côte d'Ivoire would all be at risk, with the latter two

countries having lysine values below 40 mg per gram of protein. The contrast with Japan and the United States, which have lysine values above 65 mg per gram of protein, is obvious and results primarily from the far greater availability of animal protein in the latter countries. Animal protein supplies some 63% of the total protein in the United States, but the value is less than 20% in a number of the poorer countries, with Bangladesh, for example, having only 12.8% of the total protein from animal foods.

## Strategies for intervention

Strategies and activities to alleviate micronutrient deficiencies must include several approaches. The first involves improving dietary diversity by stimulating the production and consumption of micronutrient-rich foods. A complementary approach is the direct fortification of cereals with micronutrients, including synthetic amino acids. The former option of increasing the availability of animal foods and legumes is highly constrained in most societies by social and economic factors. Fortification of basic foods is, nevertheless, a short-term intervention that has proven to be very effective (e.g., iodization of salt). Fortification is especially applicable to cereals used in a milled form, but difficulties arise where there are multiple small-scale producers. Where large centralized milling facilities exist, it is more straightforward. Additional requirements for successful fortification are the adoption and enforcement of appropriate legislation as well as the convincing of both consumers and professionals that such plans are to their benefit.

TABLE 2. Food energy, protein (total, animal, cereal, and pulse-soy), and estimated lysine values for selected groups of countries

Region	Population (millions)	Food energy (kcal/day)	Total protein (g/day)	Animal protein (%)	Cereal protein (%)	Pulse-soy protein (%)	Lysine (mg/day)	Lysine (mg/g protein)
North America developed	316.9	3,708	113.2	62.9	22.2	2.5	7,419	65.5
European Union	377.2	3,539	108.2	60.3	24.9	2.3	6,917	63.9
South America	350.6	2,854	75.8	49.9	29.8	9.8	4,779	63.1
Developed countries	1,317.6	3,285	99.4	56.1	29.2	2.8	6,167	62.0
World	6,110.4	2,807	76.0	37.0	42.5	7.8	4,039	53.1
Asia	3,706.6	2,701	71.3	29.9	48.0	9.5	3,547	49.7
Developing countries	4,792.6	2,675	69.6	29.5	47.8	9.6	3,454	49.6
Sub-Saharan Africa	620.4	2,229	53.9	19.5	49.5	12.6	2,466	45.8
Africa	809.5	2,444	61.5	21.0	53.3	10.2	2,762	44.9

Source: Food and Agriculture Organization/Faostat (2004) [13]. Data for 2001.

Lysine values in milligrams per day were calculated from the equation: lysine =  $(86.3 \times \text{animal protein g/day}) + (19.8 \times \text{cereal protein g/day}) + (63.6 \times \text{pulse-soy protein g/day}) + 599$  [8]. Lysine values in milligrams per gram of protein were derived by further dividing by the amount of total protein.

TABLE 3. Food energy, protein (total, animal, cereal, and pulse-soy), and estimated lysine values for selected countries

Country	Population (millions)	Food energy (kcal/day)	Total protein (g/day)	Animal protein (%)	Cereal protein (%)	Pulse-soy protein (%)	Lysine (mg/day)	Lysine (mg/g protein)
Japan	127.3	2,746	90.3	55.5	23.8	10.7	5,965	66.1
USA	285.9	3,766	114.5	63.3	22.1	2.1	7,509	65.8
Thailand	63.6	2,486	55.5	41.1	41.8	7.0	3,274	59.0
Pakistan	144.9	2,457	62.5	37.4	50.9	5.9	3,483	55.7
China	1,262.6	2,961	85.8	35.0	38.9	9.6	4,371	50.9
South Africa	43.7	2,961	85.8	35.0	38.9	9.6	4,371	50.9
Syria	16.6	3,038	74.6	25.7	57.1	4.7	3,322	44.5
Bangladesh	140.4	2,187	46.8	12.8	75.9	6.2	2,004	42.8
Nigeria	116.9	2,747	61.8	13.8	51.3	13.8	2,501	40.5
Egypt	69.1	3,385	96.5	20.4	61.2	7.0	3,902	40.4
Morocco	30.4	3,046	83.4	18.7	68.1	4.9	3,331	39.9
Côte d'Ivoire	16.3	2,594	51.2	17.8	49.2	1.0	1,915	37.4

Source: Food and Agriculture Organization/Faostat (2004) [13]. Data for 2001.

Lysine values in milligrams per day were calculated from the equation: lysine =  $(86.3 \times \text{animal protein g/day}) + (19.8 \times \text{cereal protein g/day}) + (63.6 \times \text{pulse-soy protein g/day}) + 599$  [8]. Lysine values in milligrams per gram of protein were derived by further dividing by the amount of total protein.

### Human studies of lysine fortification

In some studies using the 1973 Food and Agriculture Organization/World Health Organization [14] scoring pattern, it was observed that the content of sulfur-containing amino acids and tryptophan in cereal proteins was substantially higher than requirement values, but that lysine was limiting. Despite this lack, however, it was possible to achieve useful amounts of protein intake from cereals if they were consumed in sufficient quantities. However, it was later shown [15] that the consumption of sufficient amounts of cereal protein to meet protein and lysine requirements was difficult for infants and preschool children because of the large volume of food required. Graham and his associates [16] demonstrated in 1969 that a one-year-old infant with a lysine requirement of 90 mg per kilogram of body weight per day and a food energy requirement of 90 kcal per kilogram of body weight per day, consuming only wheat flour (11% protein, 2.5 g lysine/100 g protein), would have to eat 327 g of wheat flour daily to meet his or her lysine requirement. Not only would this volume of food be impossible to ingest, but such an intake would lead to excessive food energy intake, with low levels of micronutrients.

Studies conducted in the 1950s and 1960s on children recovering from protein-energy malnutrition demonstrated that lysine was important in improving nitrogen retention when wheat or corn was the staple food. Scrimshaw and his associates [17] examined the effects of amino acid imbalances and the addition of simple amino acids on the nitrogen retention of children consuming a corn masa diet. Despite the limited number of trials and their short durations, it was found that the children were sensitive to small changes in the

amino acid content of their diets. When lysine and tryptophan (the two limiting amino acids) were added to corn masa in the diet (3 g protein per kilogram of body weight per day and 100 kcal per kilogram of body weight per day), so as to approximate the then recommended FAO reference pattern, nitrogen retention was markedly improved in both cases. Working at the Institute of Nutrition of Central America and Panama (INCAP), Bressani et al. [18] observed similar results using 2.0 and 1.5 g protein per kilogram of body weight per day and a corn masa basal diet. They then conducted a study using wheat as the source of plant protein [19]. It was noted again that in the utilization of wheat protein, lysine was the most limiting amino acid. Addition of lysine to the basal diet resulted in sustained nitrogen retention similar to that obtained with milk feeding, and when the basal diet was supplemented with all of the limiting amino acids, the retention matched that of the FAO reference pattern. Further confirmation was later reported by the same group [20]. Similar studies were conducted using lime-treated corn and rolled oats as basal diets [21, 22]. The corn basal diet was improved by the addition of lysine and tryptophan, whereas the rolled oats basal diet had less marked amino acid deficiencies than the wheat or corn diet.

In a study of adults under hospital conditions in 1949, Hoffman and McNeil [23] found that patients given a gluten preparation with 4% lysine had a significantly higher nitrogen balance index than those given a gluten preparation without lysine. Bricker and associates [24] had even earlier shown increased nitrogen retention when a diet based on white bread was supplemented with lysine.



## Population studies

Based on the findings and recommendations of the 1969 Conference on the Amino Acid Fortification of Protein Foods held at MIT in Cambridge, Massachusetts, USA [25], three population-based studies were designed in the early 1970s. These large-scale village trials were subsequently conducted in Thailand (1971–75), Tunisia (1970–75), and Guatemala (1972–76). In Thailand, rice in the diets of preschool children was fortified with lysine, threonine, thiamine, riboflavin, vitamin A, and iron. In Tunisia, wheat was fortified with lysine, iron, and vitamins in a malnourished population in the southern part of the country. In Guatemala, corn (maize) was fortified with lysine, vitamins, and minerals. All three studies involved physical examination, anthropometry, collection of blood samples for hemoglobin and hematocrit, and collection of morbidity and mortality information. None of the studies reported any significant beneficial health effects. Some years after the completion of the studies, a task force was formed [26], with one of its objectives being to examine each of the studies (design, approach, analysis and interpretation of data, project management, and budget costs). For all three studies, examination revealed serious flaws in design, methods, or analysis.

As a result of the recognition of these failures, together with a reduction in international interest in protein deficiency and protein requirements, no further lysine-fortification trials took place until the currently reported studies from Pakistan and China [1, 2]. No attempt will be made to outline these studies, since they can be reviewed in the abstracts. Nonetheless, the results of both indicate that lysine fortification of wheat flour may significantly improve sensitive indicators of nutritional status in populations consuming diets in which 57% to 67% of the protein originates from wheat. It should be noted that at the time the studies were conducted, the average dietary lysine values from food balance sheet data were lower than the relatively acceptable values from 2001 shown in table 3. Furthermore, in the region of China where the study took place, near Huixian City in Henan Province, wheat was the major staple rather than rice.

As has been indicated earlier, the addition of a synthetic form of lysine to improve protein quality is not a new concept, and fortification with synthetic amino acids is a procedure that is widely used for animal feeds in the developed regions of the world. Production and use of l-lysine in animal feed started in Japan in the 1960s. l-Lysine HCl is especially important in pig feed, as it is the first limiting amino acid for growing pigs. The rationale for the addition of crystalline amino acids is that it is a more efficient form of converting feed proteins to meat, as it reduces the costs of additional protein sources [27]. It may also lead to

an improved efficiency of utilization of limited arable land. Furthermore, nitrogen excretion due to animal farming can be a considerable threat to human health because of pollution of soil and water by ammonia or nitrates and nitrites. By supplementing the diet with amino acids, one can actually decrease the overall protein level in feeds, thereby reducing the risk of nitrogen pollution. Worldwide production of lysine for feed is considerable, and it has been estimated that 500,000 to 600,000 metric tons of l-lysine HCl was produced in the year 2000 [27].

## Summary and conclusions

Fortification with lysine to improve the protein value of human diets that are heavily based on cereals has received support from the results of these recent studies [1, 2]. Support also comes from examination of average food and nutrient availability data derived from food balance sheets. Whereas nutritional status is influenced by the nutrient content of foods consumed in relation to need, the requirements for protein and amino acids are influenced by many additional factors [10, 12, 14, 28, 29]. These include age, sex, body size, physical activity, growth, pregnancy and lactation, infection, and the efficiency of nutrient utilization. Even if the immune response was influenced by the added lysine, adequate water and basic sanitation would remain essential.

Acute and chronic undernutrition and most micronutrient deficiencies primarily affect poor and deprived people who do not have access to food of adequate nutritional value, live in unsanitary environments without access to clean water and basic services, and lack access to appropriate education and information [30]. A further variable is the possible interaction between protein and food energy availability [31]. This could affect the protein value of diets when food energy is limiting to a significant degree. Thus, the additional effects of food energy deficiency on protein utilization could well be superimposed on the very poorest.

The improvement of dietary diversity must be the long-term aim, with dietary fortification considered only a short-term solution. The former should take place as wealth improves and the gaps between rich and poor diminish. Although such changes are taking place, they are highly uneven. Over the last several decades, increases have occurred in the availability of food energy, total protein, and animal protein for both developed and developing countries. However, for the very poorest developing countries over the same period, changes have been almost nonexistent, and the values for some nutritional indicators have even declined. For estimated lysine value, the developed countries showed increases in per capita availability from 5,400 to 6,167 mg per day and the developing countries from 2,400 to 3,454 mg per day, while in contrast, the very poorest

countries remained static at about 2,400 to 2,500 mg per day.

Thus, although lysine fortification may be theoretically only a short-term solution, in the very poorest countries changes in wealth such that dietary diversity and lysine availability may increase by natural progres-

sion remain remote. If we can justify using lysine to fortify animal feed in the rich regions of the world for economic gain, perhaps we should now consider adding lysine to the flour consumed by the deprived people in the poorest regions of the world to improve both their nutrition and their resistance to disease.

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# Lysine fortification of wheat flour improves selected indices of the nutritional status of predominantly cereal-eating families in Pakistan

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## Abstract

Wheat provides more than 50% of the protein and calorie intake of the population of Pakistan. Legumes and animal protein that could complement the amino acid pattern of wheat, in which lysine is the first limiting amino acid for utilization of protein, are not affordable by members of lower socioeconomic groups in developing countries. The purpose of the study was to determine whether lysine fortification of wheat flour would have a positive impact on populations consuming a predominantly wheat-based diet. A double-blind study was carried out for three months on the outskirts of Peshawar, Pakistan. Forty families received wheat flour fortified with lysine, and 40 families received wheat flour without lysine. Wheat provided 59% of the protein for men, 65% for women, and 58% for children. The weight and height of the children in both groups increased during the study, but the increase was significantly greater in the lysine group. Hemoglobin increased significantly in the women receiving lysine-fortified flour. Transferrin levels increased significantly in men, women, and children in the lysine group as compared with those in the control group. Prealbumin increased significantly in adults receiving additional lysine but decreased in children. Men, women, and children in the lysine-supplemented families had sig-

nificant increases in CD4, CD8, and complement C3 as compared with controls. These results indicate that lysine fortification of wheat flour can significantly improve sensitive indicators of nutritional status in a population consuming a diet in which 58% to 65% of the protein, depending on age and sex, is supplied by wheat.

**Key words:** Fortification, immunological status, lysine, nutritional status, Pakistan, wheat flour

## Introduction

Mild to moderate protein-energy malnutrition affects 52% of all children two to five years of age in Pakistan, as indicated by low weight-for-age [1]. At the national level, 25% of newborns have birthweights less than 2,500 g, indicating a high prevalence of maternal undernutrition. Approximately 65% of children under five and 55% of women are anemic [2]. The infant mortality rate is 90 per 1,000 live births, and maternal mortality is 500 per 100,000 [2].

The poor of developing countries have traditionally complemented the protein of their predominantly cereal diet with a source of better-quality protein that supplies enough of the limiting amino acid in cereal protein to increase the overall utilization of dietary protein to an acceptable level. In Latin America the source is a combination of maize and beans; in China and East Asia it is rice and soybean; and in South Asia it is most commonly wheat and a variety of legumes, including mung bean, Bengal gram, green gram, and groundnut (peanut). Cereal diets are frequently supplemented by small amounts of fish or other animal protein when these can be afforded.

The main dietary staple of Pakistan is wheat flour, consumed three times daily in the form of a circular flat bread, along with small amounts of legumes and pulses cooked in the form of a curry. Wheat constitutes approximately 80% of the total cereal intake, and it contributes 50% of total energy and 60% of total

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Mention of the name of firms and commercial products does not imply endorsement by the United Nations University.

protein intake [2]. Since lysine is the first limiting amino acid for utilization of wheat protein, high-wheat diets must be complemented in some way to improve their amino acid pattern [3]. Either animal or legume protein will do this. Unfortunately, sufficient animal protein is usually not affordable, and legume production has lagged [4] and its price has soared beyond the reach of the most vulnerable groups [5].

The nutritional quality of food protein is determined by how well the content of the specific essential amino acids in the protein meets the requirement for each of these. The amino acid score of a protein is calculated by comparing its amounts of individual essential amino acids with the pattern of the requirement for each per unit of its protein. On the basis of the Food and Agriculture Organization/World Health Organization (FAO/WHO)[6] reference amino acid pattern, wheat has a protein score of 50, with lysine the first limiting amino acid in cereal. Nitrogen balance studies in rats [7] and humans [8] indicate a net protein utilization of about 50% for wheat protein, compared with nearly 100% for meat, milk, and eggs [9].

Improvement in nitrogen retention of wheat protein with lysine supplementation has been repeatedly confirmed in experimental animals [10]. It has also been confirmed by child growth studies [11–14] and nitrogen balance studies in infants [15–17], children [18–20], and adults [21–25]. All of these studies have been performed with “captive” populations (in hospitals, orphanages, schools, and universities). The only major population field trial of lysine supplementation of wheat flour was reported in 1976 from Tunisia [26]. No effect was found, but the study was seriously flawed because the investigators were unable to control either the entry of contraband flour or differences in infectious disease between experimental and control areas. Nevertheless, the failure of this trial and the decreased interest in protein deficiency have discouraged any further studies of lysine fortification of wheat flour for humans since 1976.

As a result of the increasing cost of legumes as well as animal protein to complement the predominantly wheat diets of Pakistan, the protein quality of these diets often fails to meet optimal protein needs. There is a need to re-explore the possible value of lysine fortification of wheat flour distributed to individuals who receive a majority of their dietary protein from wheat. If fortification could be shown to be effective, there are many other developing countries to which the findings would be immediately applicable. Moreover, fortification of wheat flour with iron and folic acid is already being implemented in some of these countries, including Pakistan. Therefore, the cost of adding lysine to the fortification premix would be reduced.

In order to determine whether lysine fortification of wheat flour could benefit populations consuming a diet in which wheat was the major source of protein,

a controlled double-blind study was carried out in a poor community near Peshawar, the capital city of the North West Frontier Province (NWFP). The Research Project Appraisal Committee of the Faculty of Nutrition Sciences, NWFP Agricultural University, approved the study, and the field director personally obtained the consent of all of the families after a detailed explanation of the study.

## Materials and methods

### Sample

The study village of Palosi is situated 2 km from the main campus of the NWFP Agricultural University and about 10 km from Peshawar. It has about 500 households and a population of 3,500 to 4,000 people. Eighty families of low socioeconomic status, consuming wheat-based diets, were identified. Two groups of 40 families were selected randomly from the list of 80 families. The families selected agreed to consume only the flour that was provided without charge during the study period, to provide socioeconomic and dietary data, to furnish weekly morbidity data, and to allow blood samples to be drawn at the beginning and end of the study. The father, mother, and one child between 5 and 10 years old in each family were selected for collection of dietary data, stool samples for detection of parasites, and initial and final blood samples for a number of biochemical and immunological determinations.

### Socioeconomic data

Socioeconomic information was gathered during visits to households by direct observation, interviews with mothers and fathers, and a questionnaire.

### Food consumption

Before the study started, food-consumption data were obtained from each of the three target individuals in each family by 24-hour dietary recall on two occasions a week apart, and the results were averaged. The mothers provided help in dietary recall for their children. Cooking utensils were measured to improve the accuracy of the food-consumption data. Nutrient intakes were calculated using the food-composition table for Pakistan [27].

### Anthropometry

Weight, height, and triceps skinfold thickness of the 240 subjects were measured at the beginning and the end of the three-month experimental period according to World Health Organization guidelines [28]. Of the targeted children, 56% were stunted or

wasted. Contributing causes included poverty, intestinal helminths, poor sanitation, and lack of personal hygiene. No cases of kwashiorkor or marasmus were seen, but fatigue and listlessness among children were common.

### Morbidity

All families in the study were visited by a woman physician in their homes every two weeks to record morbidity. The data were compiled during 18 visits over six months from October 8, 1996, to March 30, 1997. The focus was on respiratory and diarrheal infections among children and their mothers.

### Provision of fortified and unfortified wheat flour

The wheat flour was purchased from government utility stores. A ribbon-type blender was used to add 120 g of L-lysine monohydrochloride, supplied by Ajinomoto (Tokyo, Japan), to each 20 kg of wheat flour for fortification at a rate of 0.6 g lysine/100 g wheat flour. This was designed to bring the proportion of lysine in the protein of the fortified wheat to the levels of the 1991 FAO/WHO reference protein [6]. Subsequent FAO/WHO/United Nations University (UNU) expert consultations have reached tentative agreement on a new amino acid reference protein pattern based closely on that proposed by Young et al. [29]. The proportion of lysine, 0.45 mg per gram of protein, was the same in both patterns, but the values for several of the other amino acids differed slightly. The bags of fortified and unfortified flour were distinguished only by a slight difference in the shade of the gray thread with which the bags were stitched. The color that corresponded to the fortified flour was known only to the project coordinator in Islamabad.

The wheat flour was distributed weekly to all 80 families in the study. In agreement with the families, the quantity was based on the estimated household need. If they demonstrated that they needed more, it was provided. No attempt was made to monitor the intake of individuals.

### Monitoring wheat consumption

Before the start of the experiment, each family's flour need was estimated, and this amount was provided. No family required more than 20 kg of wheat flour per week. A questionnaire was used to monitor wheat flour consumption every two weeks. None of the members of the 80 families complained about the taste, color, or acceptability of the wheat flour.

### Examination for intestinal parasites

Stool samples were collected in their homes from each

target child and preserved in 10% formate saline (10% formate +0.9% NaCl). The specimens were emulsified in formate saline, and an aliquot was washed with tap water and filtered. One drop of the resultant filtrate was stained with Lugol's solution and examined microscopically under a cover glass.

### Laboratory determinations

From each subject, 8 ml of venous blood was collected, of which a few drops were used for hemoglobin determination with a HemoCue [30]. Then 3.5 ml was transferred to tubes with heparin EDTA to prevent clotting. The remainder was centrifuged at 3,000 RPM for 10 minutes within two hours of collection. The serum was separated, and 50  $\mu$ l of sodium azide per milliliter was added as a preservative. The serum was packed in ice and transported by air from Peshawar to the laboratory in Islamabad on the same day it was collected, and it was stored at  $-70^{\circ}\text{C}$  until analyzed. The plasma fraction for lymphocyte cell subsets was processed within 48 hours.

Prealbumin, transferrin, and complement fraction C3 were measured by radial immunodiffusion (RID) kits (Bindarid, Birmingham, England). Ferritin was measured by a specific enzyme immunoassay (EIA) kit (Ramco Laboratories, Houston, Tex., USA). The lymphocyte cell subsets were counted using immunofluorescence (Immunology Manual, Department of Immunology, St. Thomas Hospital, London). Monoclonal antibodies that bind specifically to individual T-cell types were used to identify CD4 (helper) and CD8 (suppressor) cells.

### Statistical procedures

The paired *t*-test, assuming a two-tailed distribution, was used to determine the significance of the differences between the lysine and control groups for all variables.

## Results

### Socioeconomic characteristics

Data on the socioeconomic characteristics of the study village are presented in table 1. Having a larger number of sons in the family is considered security against death from family feuds and other causes. Such an attitude reflects a lack of education. Eighty-eight percent of the men were illiterate, and none of the women had any education. Of the 12% of the men who were educated, 20% had an education up to the 10th grade, 8% up to the 4th grade, and the remainder had only a limited religious education. All inhabitants of the village were Muslim.

TABLE 1. Characteristics of families ( $N = 80$ )

Characteristic	Value
No. of persons in the household	$7 \pm 2$ (SD)
Any education (%)	
Mother	0
Father	12
Housing (%)	
Owned	96
Rented	4
Mud	94
Cement	6
Ownership of farm animals (%)	
Cow	0
Goat or sheep	30
Chicken	60
Water source (%)	
Tube well	37
Unprotected hand-dug well	63
Nonpit latrine (%)	90
Land availability >4 kanal (2 acres)(%)	96
Major source of income for men (%)	
Farming	20
Unskilled labor	45
Low-grade government employee	30
Other	5
Average monthly household income (rupees) <sup>a</sup>	2,200
Children 6-14 yr old attending school (%)	60

a. 46 rupees = US\$1.

All households were headed by and economically dependent on a male. Nearly all families (96%) owned their houses, and the remainder lived in houses that were rented or offered free by landlords in return for service. A typical house had one or two rooms with mud walls and dirt floors and no proper ventilation. Most families lived in these mud houses, and only 6% lived in cement houses. However, 83% of the houses had electricity.

The majority of the families lived in walled compounds. A small, partially enclosed area with no sewer or drainage was reserved for defecation of women and children. Men used the fields for defecation. The majority of the families (63%) used water from an open, unprotected, hand-dug, uncemented well, either in the house or outside in the compound. The eco-

nomics costs of constructing pipelines and the annual or biannual water charges levied by the municipality are beyond the reach of these families. The remaining families had tap water in their houses flowing from tube wells constructed by the municipality. Food was usually prepared in a separate area located inside the house. Most had an earthen oven (tandoor) for baking bread, and 91% used wood as fuel for cooking and baking. The remaining families prepared foods using an electric or gas burner.

Household possessions were limited largely to cooking utensils, serving plates, and earthen pots for storing wheat grain and water. Half of the families surveyed had a radio, but none had television. However, 25% of the families had a bicycle, and two had motorcycles. None of the families possessed a cow or buffalo, but 30% owned one or two goats or sheep and 60% raised poultry, a traditional profession for the poorer segment of rural society areas.

Forty-five percent of the men worked as daily wage laborers; 30% were low-grade employees in governmental or semigovernmental departments (autonomous bodies mostly funded by the government); 20% were agricultural laborers; and 5% worked in various other activities. Due to the rapid growth of the population (2.9%), much of the cultivatable land is being converted to housing, and the number of persons in the village involved in farming is slowly declining. The average monthly household income was Rs 2,200/- (US\$48 by the exchange rate at the time of the study).

An important change in the village seems to be the realization of the importance of education. Although the village has a very low literacy rate for adult males and a zero rate for adult females, it is worth noting that 60% of the children aged 6 to 14 were enrolled in schools either within or outside the village. The village has one basic health unit, which also provides maternal and child health care.

### Dietary intake

Data on average protein and energy intakes are given in table 2. The average daily energy intakes of the children, women, and men of the sample population, calculated from the two dietary recall surveys, were 1,185, 2,057, and 2,269 kcal, respectively. These average energy intakes were all lower than the Pakistani recom-

TABLE 2. Protein and energy intake and sources

Subjects	Protein				Energy			
	Total (g/day)	Wheat (%)	Animal (%)	Other (%) <sup>a</sup>	Total (kcal/day)	Wheat (%)	Animal (%)	Other (%) <sup>a</sup>
Men	64	59	20	21	2,269	63	20	17
Women	57	65	18	17	2,057	58	22	20
Children	33	58	24	18	1,185	53	27	20

a. Mainly legumes.

mended dietary allowance (RDA), which is 1,265 kcal for children aged 6 to 14 years, 2,160 kcal for women, and 2,550 kcal for men.

The average daily protein intake of the children (33.0 g) was lower than the RDA for Pakistani children aged 6 to 14 years (42–56 g) [31]. However, the values of 57 g for women and 64 g for men were similar to the Pakistani RDAs. It should be noted that the Pakistani RDAs for protein allow for the poor quality of the protein in the predominantly cereal diet and for this reason are higher than those estimated from multicountry studies sponsored by UNU [32] and FAO/WHO/UNU [33].

Wheat flour contributed 58%, 65%, and 59% of the protein intake and 53%, 58%, and 63% of the energy intake of children, women, and men, respectively (table 2). Among children, wheat provided 58% of dietary protein, with 18% from other vegetable sources and 24% from animal sources. Among women, wheat provided 65% of dietary protein, with 17% from other vegetable sources and 18% from animal sources. For men, the corresponding percentages were 59%, 21%, and 20%. The total daily protein intake ranged from 44 to 68 g for women and from 18 to 65 g for children. Cereal protein intake ranged from 10 to 52 g for men, from 30 to 48 g for women, and from 10 to 35 g for children.

### Anthropometry

Baseline data for weight, height, body mass index, and triceps skinfold thickness for adults are given in table 3. They did not change significantly during the study. Both groups of children showed the expected increases in weight and height during the three-month period, but the gains in weight and height were significantly greater in the lysine group (table 4). However, the initial weights and heights were higher in the control group due to large random differences in the age distribution of the children in the two groups. The control group had only 2 children in the 5- to 7-year age group, compared with 12 in the lysine group. By contrast, the control group had 14 10-year-olds and the lysine group only 4.

### Laboratory findings

#### Parasites

Parasitic infections were found in 68% of the children. *Ascaris lumbricoides* (33%), *Entamoeba histolytica* (25%), *Hymenolepis nana* ova (18%), and *Giardia lamblia* cysts (16%) were the most common parasites in this population.

#### Transferrin and prealbumin

The values for transferrin and prealbumin are given in table 5. In both the control and the lysine groups, the increase in transferrin at the end of the study was significant for women. However, the difference for men and women in the increase in transferrin was far greater in the lysine than in the control group. For men and women, prealbumin increased significantly in both treatment groups, but the increase was greater in individuals receiving lysine-supplemented flour. Prealbumin decreased significantly in the control group of children and increased significantly in the lysine-supplemented group.

#### Immunology

The results for complement fraction C3 and for CD4 and CD8 T cells are given in table 5. All three measurements increased significantly in all family members in the group receiving lysine as compared with those in the control group. CD4 and CD8 cells generally decreased in the control group and increased significantly in the group receiving lysine. The significance

TABLE 3. Selected baseline anthropometric measurements for adults ( $N = 39$  for each group)

Measurement	Men		Women	
	Control	Lysine	Control	Lysine
Weight (kg)	57.8	56.8	57.8	56.2
Height (cm)	165.7	162.6	156.5	154.8
Body mass index (kg/m <sup>2</sup> )	21.0	20.6	23.6	23.4
Triceps skinfold thickness (mm)	12.1	13.3	7.7	7.8

TABLE 4. Anthropometric measurements of children at the beginning and end of the study ( $N = 39$  for both groups)

Measurement	Control			Lysine			L – C <sup>c</sup>
	Start	End	C <sup>a</sup>	Start	End	L <sup>b</sup>	
Weight (kg)	26.1	26.6	*	22.7	23.6	*	*
Height (cm)	130	132	*	118	121	**	*
Body mass index (kg/m <sup>2</sup> )	15.5	15.3	NS	16.3	15.9	NS	NS
Triceps skinfold thickness (mm)	6.8	6.1	NS	7.1	6.6	NS	NS

\*  $p < 0.05$ ; \*\*  $p < 0.01$ ; NS, not significant.

a. C is the difference between the initial and final values for the control group.

b. L is the difference between the initial and final values for the lysine group.

c. L – C is the difference between the preceding two values, i.e., the change in values for the lysine group minus the change in values for the control group.



TABLE 5A. Transferrin, prealbumin, and T-cell populations at the beginning and end of the study in men

Measurement	Control			Lysine			L - C <sup>c</sup>
	N	Start	C <sup>a</sup>	N	Start	L <sup>b</sup>	
Transferrin (mg/dl)	35	431	4	32	384	135*	132*
Prealbumin (mg/L)	36	280	21*	34	260	27*	6*
Complement C3 (mg/L)	36	995	206*	34	979	349*	143*
CD4 cells (%)	24	11.5	-1.5	21	8.0	3.7*	5.4*
CD8 cells (%)	23	5.9	-0.8	20	3.9	7.0*	3.4*

\*  $p < 0.05$ .

TABLE 5B. Transferrin, prealbumin, and T-cell populations at the beginning and end of the study in women

Measurement	Control			Lysine			L - C <sup>c</sup>
	N	Start	C <sup>a</sup>	N	Start	L <sup>b</sup>	
Transferrin (mg/dl)	34	438	39*	30	412	126***	87**
Prealbumin (mg/L)	35	251	13*	30	264	40*	27*
Complement C3 (mg/L)	27	1,262	86*	29	1,044	378*	292*
CD4 cells (%)	22	14.6	-1.5	21	13.5	2.4*	3.9*
CD8 cells (%)	22	6.6	0.3	20	8.3	1.7*	1.4*

\* $p < 0.05$ ; \*\* $p < 0.02$ ; \*\*\* $p < 0.01$ .

TABLE 5C. Transferrin, prealbumin, and T-cell populations at the beginning and end of the study in children

Measurement	Control			Lysine			L - C <sup>c</sup>
	N	Start	C <sup>a</sup>	N	Start	L <sup>b</sup>	
Transferrin (mg/dl)	35	431	4	32	380	146**	30**
Prealbumin (mg/L)	36	218	22	33	249	-13	35*
Complement C3 (mg/L)	36	1,080	42	34	979	349*	43*
CD4 cells (%)	24	18.5	-1.7	22	7.8	3.6*	5.3*
CD8 cells (%)	24	8.6	-2.2	22	3.9	4.2*	1.9*

\* $p < 0.05$ ; \*\* $p < 0.01$ .

a. C is the difference between the initial and final values for the control group.

b. L is the difference between the initial and final values for the lysine group.

c. L - C is the difference between the preceding two values, i.e., the change in values for the lysine group minus the change in values for the control group.

of the randomly lower initial values for CD4 and CD8 among children in the lysine group is unknown. C3 also increased significantly in men and women in the control group, but not as much as in the group receiving lysine. The values were on the low side of the normal range of 910 to 1,567 mg/L.

### Hemoglobin

Among women receiving fortified flour, there was a significant increase in hemoglobin that may have been influenced by the lower initial values. There were no other differences in hemoglobin levels between the control and lysine fortification groups (table 6).

### Disease frequency

There were no significant differences between the con-

TABLE 6. Hemoglobin values (g/dl) at the start and end of the study ( $N = 39$  for both groups)

Subjects	Control		Lysine	
	Start	End	Start	End
Men	11.2	11.7	11.6	11.8
Women	9.6	9.6	8.8	9.6 <sup>a</sup>
Children	9.4	9.4	9.5	9.8

a. The difference in hemoglobin between the start and end of the trial was significant for women ( $p < 0.01$ ). Other differences between the start and end of the trial and between control and lysine groups were not significant ( $p > 0.05$ ).

rol and lysine groups in morbidity from diarrheal and respiratory diseases. In the two visits during the first month, an average of 43% of the children had respiratory infections and 46% had diarrhea. In the two visits

during the final month, 45% had respiratory disease and 33% had diarrhea. A small number of adult males had throat and respiratory infections. Seasonal variation was the most likely reason for the small decrease in child morbidity from the first to the third month.

## Discussion

Visceral serum proteins, such as albumin and transferrin, are directly related to protein nutritional status. However, because of its relatively long half-life of 20 days, albumin is slower to reflect short-term nutritional changes. With its shorter half-life of 7 to 10 days, transferrin is more responsive to improvement in protein status [34], as is serum prealbumin [35]. Both transferrin and prealbumin significantly increased in the men and women receiving lysine as compared with the control group, with the effect more marked for transferrin. For children, only the improvement in transferrin with lysine supplementation was significant.

Most immune responses involve the production of proteins with specific functions. Specific immune responses such as T-cell subtypes, complement C3, and delayed cutaneous hypersensitivity are useful indicators of malnutrition [36–38].

Unfortunately, the antigens to test delayed cutaneous hypersensitivity lost their potency by the time they reached the study site. However, the measures of transferrin, prealbumin, complement C3, and C4 and C8 T cells all showed significant increases in the group receiving lysine-fortified wheat flour. This can reasonably be attributed to the effect of lysine in improving the overall protein quality of the diet.

Serum C3 also increased in the control group, but less than in the fortification group. In well-nourished individuals, C3 increases in response to infection, but in those who are poorly nourished, it remains the same or falls [39]. The increased C3 in all groups could be attributed to a seasonal increase in infection, and the greater rise in C3 in the families in the lysine-fortification group to better nutritional status.

An attempt was made to determine whether the positive responses of transferrin, the C3 complement fraction, and CD4 and CD8 T cells were limited to those in the lower socioeconomic groups, but this was not the case. However, this suggests that a relatively poor protein digestibility and quality made most of the protein intakes suboptimal.

The significant increase in hemoglobin among women in the lysine-supplemented families was not anticipated, since there was no difference in the iron content of the two diet groups. It can be speculated that the increase in transferrin, the transport protein

for iron, was sufficient to improve iron absorption and/or transport. Serum ferritin, an indicator of iron stores, was also measured at the end of the study, but the overall differences between the two groups were not statistically significant.

Where significant improvements were observed in the control group, it is presumed that an increase in wheat available to the family or the cash saved by receiving free wheat may have been responsible. It is noteworthy that these effects of improving the protein quality of the diet with lysine fortification were observed in a population with apparently adequate mean total protein intake. As described above, the predominantly wheat-based diet of Pakistan has a lower protein quality than diets with more protein from legumes and animal sources. Moreover, although the mean protein consumption is adequate, there is wide variation in intake, so that a large number of individuals actually have marginal or low protein intake.

For the 40% of Pakistan's 140 million people who are below the poverty line, improving the protein quality of their diet through increased consumption of animal food such as meat, eggs, and milk is not economically feasible. Moreover, the traditional sources of complementary amino acids, such as legumes and pulses, are no longer affordable by a large segment of the Pakistani population.

A national survey found that 76% of the protein intake in Pakistan is derived from vegetable sources, and cereal accounts for 65% of the total protein intake [2]. In the present study, the percentages of total protein provided by cereal were similar: 59% for men, 65% for women, and 58% for children. This supports the suggestion that the benefits of lysine fortification of wheat flour found in this study are likely to apply to most other populations in Pakistan. The main cereal, wheat, is consumed in the form of bread by rich and poor alike.

The results indicate that lysine fortification of wheat flour can significantly improve some indicators of nutritional status in a population of individuals consuming a diet in which nearly two-thirds of the protein, depending on age and sex, is supplied by wheat. Iron deficiency is even more prevalent, and iron and folate fortification of cereal flour in Pakistan is already planned. Wherever this is the case, the cost of adding lysine to the premix would be reduced. Since policies cannot be based on one study in one location, it is important that the study design be replicated as soon as possible in another country and population, if possible with some additional indicators of nutritional and health status. There is an obvious need to try to link the positive findings of this study to tangible health benefits.

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# Lysine-fortified wheat flour improves the nutritional and immunological status of wheat-eating families in northern China

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## Abstract

*The purpose of this study was to determine the impact of the fortification of wheat flour with lysine on selected health indicators among farm families obtaining 58% to 67% of their dietary protein from wheat. A man, a woman, and a child aged 5 to 12 years were studied from each of 88 families in a village near Huixian City, Henan Province, China. Half of the families received wheat flour fortified with 3 g of lysine per kilogram for three months, and the other half received wheat flour without fortification. The results showed a significantly greater gain in the height and weight of children receiving lysine-fortified wheat flour. Hemoglobin values were not affected. The mean prealbumin values of adult men and women were higher in those receiving lysine. The numbers of CD3 T cells increased significantly in women and children, as did the complement fraction C3 and IgG in men, IgA in women, and IgG, IgA, IgM, and C3 in children. These results indicate that lysine fortification of wheat flour can significantly improve some indicators of the nutritional status and immune function of family members consuming a wheat-based diet.*

**Key words:** China, fortification, immunological status, lysine, nutritional status, wheat flour

## Introduction

A diet dependent on cereal protein must be complemented by a lysine source to provide a balanced amino acid pattern in the total diet. Protein from either animal sources or legumes will meet this need. However, the former is often prohibitively expensive for those at risk, and legume prices have soared in recent years. Fortification of a staple food offers a possible way of correcting specific nutritional deficiencies in an underprivileged population.

Although the quality of the diet of the Chinese people has improved with the economic development of the last two decades, dietary protein continues to be derived primarily from cereals and cereal products. According to the national nutrition survey conducted in 1992 [1], an average of 66.8% of dietary protein in rural China came from cereals. The amount of legumes and animal products in the diet is still low for most rural populations. Despite the predominance of rice in the South, the staple food of 44% of the Chinese population is wheat flour [1]. On the basis of the Food and Agriculture Organization/World Health Organization (FAO/WHO) [2] amino acid reference pattern, the protein score of wheat is 50, because of its deficiency in lysine. This is confirmed by nitrogen balance studies in humans indicating a net protein utilization for wheat of about 50%, as compared with 100% for meat, milk, and eggs [3, 4].

When wheat protein is fortified with lysine, improvement in nitrogen retention has been repeatedly observed in experimental animals [5], young children [6, 7], and adults [8, 9]. In 1996–97, a field study was conducted in a predominantly wheat-eating community outside Peshawar, Pakistan [10]. For three months, wheat flour, which supplied up to 65% of the protein in the diet, was given either with or without

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added lysine to 80 families with 240 subjects. In this double-blind study, men, women, and children from the lysine-supplemented families had significant increases in serum transferrin, hemoglobin, and CD4 and CD8 cells. Given the potential practical importance of these findings and the need to replicate them, a double-blind study similar to that in Pakistan was carried out in Zhaoliuhe Village, Jitun Town, Huixian County, Henan Province, China, from March to June 1999. The proportion of dietary protein from wheat was comparable to that of the Pakistani population studied previously.

## Methods

A total of 88 families were assigned randomly to either the experimental or the control group. The project provided all of the wheat flour consumed by these families for the three months of the study, but there was no alteration of their dietary pattern and food behavior. In each family, a man, a woman, and a child aged 5 to 12 years were given a physical examination, and each provided a 5-ml blood sample at the beginning and the end of the study.

There was no significant difference in the annual income of 920 yuan (US\$115) for the control group and 904 yuan (US\$113) for the lysine-fortification group. Food-consumption data were obtained for each of the three family members by two methods: 24-hour recall for three consecutive days at the beginning and end of the trial, and food-frequency questionnaires (FFQs) at the beginning of the study, based on their usual diet for the previous year.

Before and after the study, weight, height, triceps skinfold thickness, and mid-upper-arm circumference were measured, and the body mass index for adults was calculated. Albumin, prealbumin, and transferrin in blood serum were determined in the Henan Provincial Health and Anti-Epidemic Station. A Clinical Chemistry Analyzer System (SPACE, Fairfield, NY, USA) was used for these assays with reagents imported from the United States. Hemoglobin was determined at the survey site using a 721 spectrophotometer (HICN 721, Shanghai Third Analytic Plant, Shanghai, China).

The immunological assays were done at the Department of Immunology in the Capital University of the Medical Sciences of China. The reagents were purchased from Coulter-Immunotech (Beijing, China). T-cell numbers and T-cell subsets (CD3, CD4, CD8), and the numbers of natural killer cells (NK) in blood, were determined by using a Flow Cytometer (FACS, Coulter, Miami, Fla., USA). Interleukin-2 in serum was measured by ELISA. Complement fraction C3, IgM, IgG, and IgA in serum were measured by simple agar diffusion methods. A CO<sub>2</sub> incubator was used for the lymphocyte transformation test [11].

## Institutional approvals

The protocol was reviewed and approved by the Committee on the Use of Humans as Experimental Subjects of the National Institute of Nutrition, the Henan Provincial Health and Anti-Epidemic Station, and the health and antiepidemic authorities of Huixian County, in which the study village was located. The study was explained in detail to each family, and written informed consent was obtained. All families were visited weekly to record any complaints, with the use of a follow-up questionnaire, and were interviewed for information on morbidity and food consumption.

## Lysine-fortification procedure

In order to ensure adequate mixing of the lysine with the wheat flour, a pretest was carried out and a three-step mixing method was adopted. The local wheat flour contains an average of 250 mg of lysine per 100 g. Therefore, 3.75 g of L-lysine monohydrochloride, equal to 3 g of lysine, was added to make 1 kg of fortified wheat flour. This resulted in a lysine concentration of 550 mg per 100 g of the final product. This complies with the latest published FAO/WHO reference amino acid pattern [2]. Subsequent FAO/WHO/UNU expert consultations have reached tentative agreement on a new amino acid reference protein pattern based closely on that proposed by Young et al. [12] The proportion of lysine, 0.45 mg per gram of protein, is the same in both patterns, but the values for several of the other amino acids differ slightly. The lysine was supplied by Ajinomoto, Tokyo, Japan. Analyses of successive batches of the wheat flour before and after fortification confirmed that the mixing method was satisfactory.

The sacks of fortified and nonfortified flour were marked with threads of slightly different color, but their significance was not known to the field team. The flour was distributed weekly to each household in amounts based on the household intake data collected during the preparatory stage. All data were entered into the Institute of Nutrition and Food Hygiene (INFH) computers in Beijing, and the SAS 6.12 (SAS Institute, Cary, NC, USA) program was used for their analysis. Analysis of all indicators was performed separately for men, women, and children. ANOVA and chi-square tests were used to compare the trends of differences between the control and lysine group. The level of significance was set at  $p < .05$ .

## Results

### Dietary data

The three-day food-consumption data collected before and after the experiment indicated a wheat intake of

433 to 675 g per day for adults and 253 to 319 g for children. The average intake of animal products was only 30 to 50 g per day for adults and 18 to 28 g for children. There were no fish or milk products in the diet. Food consumption was not significantly different in the lysine and control groups ( $p > .05$ ).

The intake of selected nutrients was calculated by using the food-consumption data and the Chinese food-composition table [13]. The average nutrient intake data from the baseline survey are shown in table 1. There were no significant differences between the control and lysine groups at the baseline survey ( $p > .05$ ). The average daily energy intakes of adult men, adult women, and children were about 3,300, 2,700, and 1,700 kcal, respectively.

Approximately 60% of dietary energy for adults was obtained from wheat flour, 23% from other cereals, 1% from legumes and legume products, and 3% from animal foods (mainly pork). Among children, 55% of the energy was derived from wheat flour, 26% from other cereals, 0.7% from legumes and legume products, and 3% from animal foods. Protein intakes were around 105 g, 80 g, and 50 g, respectively, for men, women, and children; 58% to 67% of their dietary protein was derived from wheat flour, 16% to 19% from other cereals, 2% to 3% from legumes and their products, and 3% to 6% from animal food.

At the end of the study, there were no significant differences ( $p > .05$ ) in nutrient intakes between the lysine and control groups, except for retinol equivalents, niacin, and selenium for men and retinol equivalents for children. The average lysine intake of the subjects was  $2,370 \pm 622$ ,  $1,931 \pm 389$ , and  $1,142 \pm 262$  mg/day for control men, women, and children, respectively, and

$4,238 \pm 1,038$ ,  $3,235 \pm 832$ , and  $2,166 \pm 644$  mg/day, respectively, for the lysine-fortification groups.

### Anthropometry

For adult subjects, there were no significant differences between the two groups before and after the study in weight, height, body mass index, mid-upper-arm circumference, and triceps skinfold. For children, this was also true for body mass index, mid-upper-arm circumference, and triceps skinfold, but as shown in table 2, the lysine group grew taller and gained significantly more weight by the end of the study.

### Laboratory determinations

#### Biochemical results

There were no significant differences between the control and lysine groups in hemoglobin, albumin, prealbumin, and transferrin for children either at baseline or at the end of the study ( $p > .05$ ) (table 3). For adults this was also true for hemoglobin, albumin, and transferrin levels, but at the end of the study the serum prealbumin concentration was significantly higher in the lysine group than in the control group.

#### Immunological results

The mean immunological values, including T-cell numbers (CD3), T-cell subsets (CD4 and CD8), NK cells, interleukin-2, lymphocyte transformation test (stimulation index), immunoglobulins IgG, IgM, and IgA, and complement fraction C3, are shown in table 4 for men, women, and children. There were no significant differences in these measurements between

TABLE 1. Nutrient intakes of subjects from baseline survey (mean  $\pm$  SD) compared with the Chinese recommended dietary allowances (RDAs)

Nutrient	Men	Women	Children
Energy (kcal)	3,348.9 $\pm$ 775.2 <sup>a</sup>	2,659.8 $\pm$ 558.5 <sup>a</sup>	1,693.6 $\pm$ 451.8 <sup>a</sup>
Protein (g)	105.2 $\pm$ 28.4 <sup>a</sup>	82.3 $\pm$ 18.7 <sup>a</sup>	50.3 $\pm$ 14.6 <sup>a</sup>
Carbohydrate (g)	605.1 $\pm$ 157.5	477.2 $\pm$ 105.3	293.9 $\pm$ 78.4
Fat (g)	54.2 $\pm$ 21.3	46.5 $\pm$ 21.7	40.2 $\pm$ 18.5
Retinol Eq ( $\mu$ g)	125.6 $\pm$ 92.3 <sup>b</sup>	116.4 $\pm$ 95.2 <sup>b</sup>	64.7 $\pm$ 58.1 <sup>b</sup>
Thiamine (mg)	2.5 $\pm$ 0.65 <sup>a</sup>	1.9 $\pm$ 0.4 <sup>a</sup>	1.2 $\pm$ 0.4 <sup>a</sup>
Riboflavin (mg)	1.1 $\pm$ 0.3 <sup>b</sup>	0.8 $\pm$ 0.2 <sup>b</sup>	0.5 $\pm$ 0.1 <sup>b</sup>
Niacin (mg)	23.6 $\pm$ 6.7 <sup>a</sup>	18.5 $\pm$ 4.7 <sup>a</sup>	10.9 $\pm$ 4.0 <sup>a</sup>
Ascorbic acid (mg)	143.6 $\pm$ 84.1 <sup>a</sup>	128.3 $\pm$ 68.1 <sup>a</sup>	57.4 $\pm$ 34.1 <sup>a</sup>
Vitamin E (mg)	38.3 $\pm$ 9.3 <sup>a</sup>	33.6 $\pm$ 10.6 <sup>a</sup>	25.5 $\pm$ 8.4 <sup>a</sup>
Calcium (mg)	682.9 $\pm$ 237.1 <sup>a</sup>	578.6 $\pm$ 188.1 <sup>b</sup>	287.6 $\pm$ 92.8 <sup>b</sup>
Iron (mg)	38.8 $\pm$ 10.3 <sup>a</sup>	31.6 $\pm$ 6.9 <sup>a</sup>	18.5 $\pm$ 4.8 <sup>a</sup>
Zinc (mg)	17.0 $\pm$ 4.5 <sup>a</sup>	13.5 $\pm$ 3.0 <sup>a</sup>	8.0 $\pm$ 2.3 <sup>a</sup>
Selenium ( $\mu$ g)	49.5 $\pm$ 13.1 <sup>a</sup>	38.6 $\pm$ 11.0 <sup>b</sup>	24.0 $\pm$ 7.3 <sup>b</sup>

a.  $\geq$  80% of RDA.

b.  $<$  80% of RDA.

TABLE 2. Anthropometric measurements of subjects at baseline and end of the study (mean  $\pm$  SD)

Measurement	Baseline		End	
	Control (n = 44)	Lysine (n = 44)	Control (n = 41)	Lysine (n = 43)
<b>Men</b>				
Body mass index (kg/m <sup>2</sup> )	21.0 $\pm$ 2.1	21.3 $\pm$ 2.3	21.7 $\pm$ 2.2	21.9 $\pm$ 2.7
Height (cm)	169.4 $\pm$ 5.9	169.7 $\pm$ 5.4	169.7 $\pm$ 6.0	169.4 $\pm$ 5.2
Weight (kg)	60.5 $\pm$ 8.8	61.5 $\pm$ 8.5	62.8 $\pm$ 9.2	63.1 $\pm$ 9.2
Mid-upper-arm circumference (cm)	27.9 $\pm$ 2.2	28.4 $\pm$ 2.5	28.6 $\pm$ 2.4	28.9 $\pm$ 2.7
Triceps skinfold thickness (mm)	7.6 $\pm$ 2.2	8.3 $\pm$ 3.9	9.1 $\pm$ 3.2	10.6 $\pm$ 5.9
<b>Women</b>				
Body mass index (kg/m <sup>2</sup> )	22.2 $\pm$ 3.3	22.7 $\pm$ 2.7	22.8 $\pm$ 3.1	23.4 $\pm$ 3.0
Height (cm)	156.3 $\pm$ 5.0	156.5 $\pm$ 4.8	155.9 $\pm$ 6.7	156.6 $\pm$ 4.7
Weight (kg)	55.9 $\pm$ 7.5	55.6 $\pm$ 7.2	55.8 $\pm$ 8.7	57.3 $\pm$ 7.7
Mid-upper-arm circumference (cm)	28.1 $\pm$ 2.8	28.4 $\pm$ 2.7	27.9 $\pm$ 3.6	28.8 $\pm$ 2.9
Triceps skinfold thickness (mm)	15.4 $\pm$ 5.1	16.5 $\pm$ 6.1	18.9 $\pm$ 6.9	20.1 $\pm$ 6.8
<b>Children</b>				
BMI(kg/m <sup>2</sup> )	14.8 $\pm$ 1.3	14.9 $\pm$ 1.9	15.1 $\pm$ 1.9	15.2 $\pm$ 2.1
Height (cm)	120.4 $\pm$ 12.8	125.4 $\pm$ 11.6	122.6 $\pm$ 13.6	128.4 $\pm$ 11.9*
Weight (kg)	21.7 $\pm$ 5.4	23.7 $\pm$ 5.9	22.3 $\pm$ 7.9	25.4 $\pm$ 6.7*
Mid-upper-arm circumference (cm)	17.3 $\pm$ 1.9	17.7 $\pm$ 2.1	18.1 $\pm$ 3.3	18.1 $\pm$ 2.4
Triceps skinfold thickness (mm)	7.1 $\pm$ 2.3	7.1 $\pm$ 2.7	8.1 $\pm$ 3.8	7.56 $\pm$ 2.6

\**p* < 0.05.TABLE 3. Biochemical measurements of subjects at baseline and end of the study (mean  $\pm$  SD)

Measurement	Baseline		End	
	Control (n = 41)	Lysine (n = 43)	Control (n = 41)	Lysine (n = 43)
<b>Men</b>				
Hemoglobin (g/dl)	16.2 $\pm$ 1.6	15.9 $\pm$ 1.8	15.4 $\pm$ 1.0	15.2 $\pm$ 0.9
Albumin (g/L)	44.1 $\pm$ 7.2	41.0 $\pm$ 7.5	39.9 $\pm$ 4.0	40.2 $\pm$ 3.62
Prealbumin (g/L)	0.29 $\pm$ 0.06	0.26 $\pm$ 0.09	0.25 $\pm$ 0.05	0.27 $\pm$ 0.06**
Transferrin (g/L)	2.74 $\pm$ 0.59	2.66 $\pm$ 0.67	2.37 $\pm$ 0.44	2.45 $\pm$ 0.05
<b>Women</b>				
Hemoglobin (g/dl)	13.7 $\pm$ 1.6	13.9 $\pm$ 1.6	13.1 $\pm$ 1.2	13.2 $\pm$ 1.0
Albumin (g/L)	45.0 $\pm$ 9.2	44.3 $\pm$ 7.9	38.7 $\pm$ 2.6	38.6 $\pm$ 3.4
Prealbumin (g/L)	0.24 $\pm$ 0.06	0.24 $\pm$ 0.06	0.20 $\pm$ 0.04	0.23 $\pm$ 0.04*
Transferrin (g/L)	3.36 $\pm$ 0.76	3.34 $\pm$ 0.90	2.56 $\pm$ 0.46	2.70 $\pm$ 0.46
<b>Children</b>				
Hemoglobin (g/dl)	13.1 $\pm$ 1.5	13.2 $\pm$ 1.6	12.7 $\pm$ 1.0	13.2 $\pm$ 0.8
Albumin (g/L)	41.0 $\pm$ 9.6	39.7 $\pm$ 10.4	39.7 $\pm$ 3.3	38.8 $\pm$ 3.5
Prealbumin (g/L)	0.18 $\pm$ 0.07	0.19 $\pm$ 0.06	0.18 $\pm$ 0.03	0.18 $\pm$ 0.04
Transferrin (g/L)	2.72 $\pm$ 0.67	2.72 $\pm$ 0.65	2.51 $\pm$ 0.37	2.53 $\pm$ 0.38

\**p* < 0.05, \*\**p* < 0.01.

the lysine and control groups for any of the age and sex groups before the study. After the study, however, adult male subjects in the lysine group showed a significant increase in CD8 (*p* < .05) as well as in IgG (*p* < .01) and C3 (*p* < .01), as compared with those in the control group. Adult female subjects in the lysine group had higher values of CD3 (*p* < .01) and IgA (*p* < .05) at the end of the study. Among children, CD3 (*p* < .01), IgG (*p* < .001), IgA (*p* < .01), and IgM (*p* < .01) increased significantly, as did C3 (*p* < .05).

## Discussion

The results of this study, together with those of the nearly identical prior study in Pakistan [10], indicate that lysine fortification can improve the nutritional status of families for whom wheat is the major source of dietary protein. Although the positive findings were not identical in this study and the similar one in Pakistan [10], more than half of the parameters measured were significantly increased in both studies. In



TABLE 4. Immunological measurements of subjects at baseline and end of the study (mean  $\pm$  SD)

Measurement	Baseline		End	
	Control	Lysine	Control	Lysine
<b>Men</b>	(n = 43)	(n = 43)	(n = 43)	(n = 41)
CD3 (%)	66.90 $\pm$ 5.46	67.29 $\pm$ 5.53	67.70 $\pm$ 5.52	69.13 $\pm$ 6.57
CD4 (%)	37.20 $\pm$ 5.39	35.61 $\pm$ 5.94	37.67 $\pm$ 6.51	36.10 $\pm$ 7.31
CD8 (%)	25.86 $\pm$ 4.99	27.74 $\pm$ 5.64	26.27 $\pm$ 6.83	29.43 $\pm$ 6.83*
NK (%)	16.27 $\pm$ 5.73	15.56 $\pm$ 6.81	15.11 $\pm$ 5.93	17.14 $\pm$ 6.84
IL-2 (OD405)	0.31 $\pm$ 0.15	0.32 $\pm$ 0.18	0.41 $\pm$ 0.06	0.44 $\pm$ 0.11
LTR (%)	0.32 $\pm$ 0.14	0.31 $\pm$ 0.14	0.58 $\pm$ 0.05	0.60 $\pm$ 0.07
IgG (g/L)	15.65 $\pm$ 5.95	15.44 $\pm$ 7.84	13.82 $\pm$ 4.40	18.83 $\pm$ 6.99**
IgA (g/L)	3.04 $\pm$ 1.33	2.85 $\pm$ 1.57	2.78 $\pm$ 1.41	3.37 $\pm$ 1.88
IgM (g/L)	1.25 $\pm$ 0.44	1.16 $\pm$ 0.29	1.36 $\pm$ 0.49	1.55 $\pm$ 0.56
C3 (g/L)	0.91 $\pm$ 0.19	0.93 $\pm$ 0.25	0.99 $\pm$ 0.10	1.10 $\pm$ 0.26**
<b>Women</b>	(n = 40)	(n = 43)	(n = 40)	(n = 43)
CD3 (%)	66.90 $\pm$ 6.14	67.51 $\pm$ 5.40	67.94 $\pm$ 5.55	71.15 $\pm$ 5.51**
CD4 (%)	38.60 $\pm$ 6.69	37.82 $\pm$ 5.35	37.58 $\pm$ 6.07	40.12 $\pm$ 6.07
CD8 (%)	25.07 $\pm$ 3.73	26.46 $\pm$ 4.83	27.30 $\pm$ 4.85	27.87 $\pm$ 5.97
NK (%)	16.72 $\pm$ 6.24	15.63 $\pm$ 5.74	14.61 $\pm$ 4.57	15.35 $\pm$ 6.73
IL-2 (OD405)	0.33 $\pm$ 0.22	0.29 $\pm$ 0.11	0.44 $\pm$ 0.08	0.42 $\pm$ 0.10
LTR (%)	0.33 $\pm$ 0.15	0.30 $\pm$ 0.12	0.61 $\pm$ 0.06	0.58 $\pm$ 0.06
IgG (g/L)	18.30 $\pm$ 8.70	17.3 $\pm$ 7.35	16.90 $\pm$ 7.73	20.15 $\pm$ 8.26
IgA (g/L)	1.50 $\pm$ 0.56	1.43 $\pm$ 0.46	1.67 $\pm$ 0.59	1.95 $\pm$ 0.69*
IgM (g/L)	2.99 $\pm$ 1.62	2.71 $\pm$ 1.64	2.88 $\pm$ 1.60	2.98 $\pm$ 1.64
C3 (g/L)	0.99 $\pm$ 0.23	0.92 $\pm$ 0.20	1.04 $\pm$ 0.14	1.05 $\pm$ 0.16
<b>Children</b>	(n = 40)	(n = 43)	(n = 40)	(n = 43)
CD3 (%)	66.83 $\pm$ 6.15	68.20 $\pm$ 5.47	66.26 $\pm$ 6.34	70.96 $\pm$ 6.34**
CD4 (%)	34.77 $\pm$ 5.78	35.32 $\pm$ 5.08	35.50 $\pm$ 6.94	37.62 $\pm$ 5.77
CD8 (%)	26.87 $\pm$ 3.78	28.18 $\pm$ 5.03	26.94 $\pm$ 4.16	29.06 $\pm$ 5.82
NK (%)	14.84 $\pm$ 5.83	13.61 $\pm$ 4.89	14.79 $\pm$ 5.50	13.81 $\pm$ 5.29
IL-2 (OD405)	0.26 $\pm$ 0.08	0.29 $\pm$ 0.14	0.42 $\pm$ 0.08	0.43 $\pm$ 0.09
LTR (%)	0.33 $\pm$ 0.14	0.31 $\pm$ 0.13	0.59 $\pm$ 0.06	0.59 $\pm$ 0.06
IgG (g/L)	12.67 $\pm$ 4.40	12.34 $\pm$ 6.19	11.51 $\pm$ 4.53	17.42 $\pm$ 8.55***
IgA (g/L)	1.27 $\pm$ 0.37	1.28 $\pm$ 0.34	1.34 $\pm$ 0.32	1.66 $\pm$ 0.52**
IgM (g/L)	1.64 $\pm$ 0.86	1.57 $\pm$ 0.76	1.52 $\pm$ 0.63	1.97 $\pm$ 1.03**
C3 (g/L)	0.98 $\pm$ 0.18	0.95 $\pm$ 0.24	1.01 $\pm$ 0.16	1.10 $\pm$ 0.19*

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$ .

CD3, CD4, CD8, and NK are T-cell subsets; IL-2 is interleukin-2; LTR is lymphocyte transformation response to a mitogen (stimulation index); IgG, IgA, and IgM are immunoglobulins; and C3 is a complement fraction.

addition, CD3 cells, not studied in Pakistan, increased in all three groups in this study, as did a number of the immunoglobulins. Wheat flour is the staple food in the north and northwest provinces of China, and lysine is known to be limiting in wheat protein. The preferred approach to correcting the lysine deficiency is improving the overall quantity and quality of the diet. However, this would require an increase in animal or legume proteins or both. For the poor of developing countries, these are costly or in short supply, and an alternative approach is required.

As summarized in the Introduction, in experimental trials in rats and metabolic studies in humans, the protein quality of wheat was improved by lysine fortifica-

tion. However, evidence for this in human populations at the household level is limited to the recent study in Pakistan, after which this study is patterned [10]. A study in the 1960s in Tunisia that failed to find an effect of lysine fortification of wheat flour was seriously confounded by contraband unfortified flour entering the experimental area, possible differential effects of infection in the villages, and low dietary energy intakes that may have been limiting [14].

In this latest study in China, the average protein intake of children of around 46 to 54 g per day was only 79% to 89% of the recommended dietary allowance (RDA), but energy intakes were adequate. Given this relatively low intake of available protein,

an improvement in protein quality with lysine fortification of wheat flour would be expected. It is not surprising, therefore, that the height and weight of children were observed to increase significantly in the lysine-fortification group as compared with those in the control group.

Although the total protein and energy intake of the adults in this study was adequate, the protein quality was poor, because the predominantly wheat diet was deficient in lysine. Serum proteins, such as albumin, prealbumin, and transferrin, are directly related to protein nutritional status. The level of prealbumin was significantly higher at the end of the study in the women receiving the lysine-fortified wheat flour, suggesting improved protein status, but no other significant changes in these serum proteins were observed.

Immune responses are adversely affected by poor nutritional status, including that of protein [15]. In subjects whose protein status is suboptimal, increasing the amount of available protein in the diet can result in improvement in sensitive immunological parameters [16].

In the current study, the women and children who received lysine-fortified flour showed significant increases in CD3 T-cell numbers. Complement C3 also increased significantly in men and children in the lysine-fortification group. The increase in all three immunoglobulins measured was highly significant in children, and the increases in IgG in men and IgA in women were significant. It is concluded that lysine fortification improved the nutritional quality of the dietary protein, as judged by an increase in some measures of immune function.

The three-month test period was too short and sanitation was too good to allow any effect on morbidity from infectious disease to be detected. During the entire study, there were only seven cases of diarrheal disease: two among children in the control group, two among women in the control group, and three among men in the lysine group. Respiratory disease was seasonally rare in the population studied, and the distribution of the small number of cases was almost identical in the

lysine and control groups.

The evidence that individuals whose dietary protein comes mainly from wheat, with only limited legume and animal protein, show improvement in some indicators of nutritional status in similar studies conducted in two different countries justifies further efficacy trials. The cost-effectiveness of multiple fortification of wheat flour should also be explored.

According to the Chinese national nutrition survey conducted in 1992 [1], the protein intake of children aged 2 to 5 years averaged only 81% to 86% of their respective RDAs, and that of children aged 6 to 17 years was 89% to 93% of their RDAs. It is not surprising, therefore, that lysine fortification of wheat flour significantly improved their growth and a number of immunological indicators.

There are 600 million Chinese people in officially defined poor areas. They are dependent on a very simple diet consisting predominantly of cereals. To improve the protein quality of their diet by increasing sufficiently the intake of animal foods such as meat, fish, eggs, and milk is currently not economically feasible, and as pointed out in the Introduction, this has become true for legumes as well. This study and the previous one in Pakistan suggest two potential approaches. There is currently a major international effort to promote the multiple fortification of cereal flours with vitamins and minerals. For some populations, the addition of lysine to this premix might be justified. Another approach could be the application of biotechnology to improve the lysine content of wheat, as has been done successfully for maize by conventional breeding [17], but conventional breeding efforts for wheat have proved more difficult.

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# Fast and reliable salt iodine measurement: Evaluation of the WYD Iodine Checker in comparison with iodometric titration

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## Abstract

*Iodine deficiency persists as the leading cause of preventable brain damage and reduced intellectual capacity in the world. The most effective method for the elimination of iodine deficiency is the consumption of adequately iodized salt. Ensuring that a population receives adequately iodized salt demands careful monitoring of the salt iodine content. We evaluated the WYD Iodine Checker, a hand-held instrument that quantitatively measures the salt iodine content on the basis of a colorimetric method, and compared its performance with iodometric titration. Performance testing results indicated that the WYD Iodine Checker is a highly precise, accurate, and sensitive tool for measuring salt iodine content. It is a user-friendly instrument that is based on a simple methodology and a straightforward salt sample preparation and testing procedure. We recommend further testing to examine the field performance of the WYD Iodine Checker when measuring iodate salt samples.*

**Key words:** Colorimetry, low-technology, portable instrument

## Introduction

Iodine-deficiency disorders are the leading cause of preventable brain damage and mental retardation, with over a billion people at risk worldwide. The

consequences of iodine-deficiency disorders not only severely threaten the growth and development of a child, but its subsequent implications also thwart the socioeconomic development of an entire population. The most cost-effective and sustainable intervention to eliminate iodine-deficiency disorders is universal salt iodization (USI), which involves the adequate iodization of all edible salt. It is critical to monitor the iodine content of salt at the production, distribution, retail, and consumption levels to ensure the quality of iodized salt and to verify advancement toward achieving USI.

Various methods are available for testing the iodine content in salt. One such method is the rapid salt testing kit, which is a field-friendly, inexpensive, highly sensitive test. The test qualitatively or semiquantitatively detects iodine in salt. To obtain a more accurate, quantitative measurement of the salt iodine concentration, iodometric titration is recommended [1]. Titration is conducted for validation, but it requires skilled personnel and is time-consuming and costly, which limits its applicability for routine monitoring of the salt iodine concentration.

One method that can be used for routine monitoring and requires simple laboratory equipment is the colorimetric procedure. Evaluation of one spectrophotometric method, based on a modified Dustin and Ecoffey iodine quantitative method, indicated that the method was highly precise, accurate, sensitive, and specific. The method also had added advantages, such as its ease of use and simple methodology [2]. A similar colorimetric method developed by the Salt Research Institute of the China National Salt Industry Corporation is the WYD Iodine Checker. The WYD Iodine Checker was evaluated by the Centers for Disease Control and Prevention (CDC) and compared with the iodometric titration method. This evaluation does not constitute an endorsement by CDC. CDC's evaluation of the method was conducted independently, and thus it was in no way commissioned or supported by the instrument manufacturer.

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Mention of the names of firms and commercial products does not imply endorsement by the United Nations University.

## Experimental methods

### Apparatus

The WYD Iodine Checker is a single-wavelength spectrophotometer that measures the iodine level (mg/kg) in salt based on the absorption of the iodine-starch blue compound at 585 nm. The manufacturer specifies that the instrument's range of measurement is 10 to 90 mg/kg and that it has an analytical error of less than two parts per million. Its weight (500 g) and dimensions (175 × 135 × 60 mm) make it easily transportable; the manufacturer states that it can withstand a damp and corrosive environment. It functions on 220V AC voltage or DC 9V, which requires six AA batteries [3].

### Solutions and reagents

The CDC chemists followed the procedures provided in the WYD Iodine Checker Manual for the preparation of solutions for testing salt iodized with potassium iodate ( $\text{KIO}_3$ ) and iodide (KI), except that 18 M $\Omega$ -cm ultra-pure water was used for the preparation of solutions and testing of salt samples. The WYD Iodine Checker manual states that distilled water, purified drinking water, or cooled boiled water can be used [3]. Measurement of salt iodized with iodate requires the preparation of a  $\text{KIO}_3$  standard solution and an iodine working standard solution, which can be used for up to six months and is equivalent to the concentration of 50 mg/kg in an iodized salt sample. It further requires the preparation of two reagents: solution A, a starch-based solution; and solution B, a sulfuric acid solution. Measurement of salt iodized with iodide requires oxidation of iodide to iodate using 3% (w/v) bromine solution, and the excess bromine solution is neutralized by 10% (w/v) sodium formate solution. After this oxidation, the same steps are performed as for salt iodized with  $\text{KIO}_3$  [3]. The cost of reagents per salt sample tested is approximately US\$0.07.

### Salt samples

Morton Salt samples with known concentrations of iodide or iodate (25, 50, 75, and 100 mg/kg) were analyzed. The Morton Salt samples did not contain a free-flow agent. Potassium iodate was used as the fortificant for the iodate salt samples, and KI was used as the fortificant for the iodide salt samples, which were stabilized with dextrose and sodium bicarbonate. Market salt samples obtained from Argentina, Brazil, Chile, and Mexico that had unknown concentrations of iodine were tested by the iodate procedure.

### Analytical methods

*WYD Iodine Checker.* All procedures were performed

according to the instructions provided in the WYD Iodine Checker manual [3]. After a zero point calibration, the instrument is calibrated using the gray glass or  $\text{KIO}_3$  standard solution to an LCD readout of  $50 \pm 0.1$ . One gram of iodized salt sample is used for the measurement. An iodate salt sample can be analyzed in about three or four minutes, which does not include the time for weighing of the salt sample. The measurement of salt fortified with KI requires oxidation of iodide to iodate before the same procedure can be followed as for salt with iodate. Therefore, the measurement of one iodide salt sample takes approximately five or six minutes, minus the sample weighing time. Testing a batch of salt samples slightly decreases the analysis time per sample, so that 20 to 30 samples can be analyzed in one hour.

### Reference method

*Iodometric titration.* The reference method for measuring the iodine content of salt is iodometric titration with the thiosulfate-starch reaction as the external indicator [1, 4]. Ten grams of iodized salt is used for the measurement; the cost of reagents per salt sample tested is approximately US\$0.06. One iodate salt sample is analyzed in roughly 15 to 20 minutes, and one iodide salt sample in about 17 to 22 minutes (minus the sample weighing time). As with the WYD Iodine Checker, testing a batch of salt samples decreases the analysis time. An estimated 12 to 15 salt samples can be measured in one hour.

### Procedures

We assessed the within-assay, among-assay, and total assay imprecision of the WYD Iodine Checker and iodometric titration. To determine the within-assay imprecision of the WYD Iodine Checker, five replicates from each of the 25 and 100 mg/kg iodate and iodide Morton Salt samples were analyzed within one day. The experiment was repeated over five individual days. First computing the standard deviation of the results measured on the same day and then dividing by the mean of the results for that day obtained the within-assay imprecision for one day. Thus, five within-assay coefficients of variation were calculated. To give a reflection of the variability of the within-assay coefficient of variation from day to day, the range of within-assay coefficients of variation was reported.

To compute the among-assay imprecision, the standard deviation from the mean result of each day was divided by the average of the mean results of each day. The total assay imprecision was determined by the standard deviation of all 25 measurements (five replicates per day over five days) divided by the grand mean of the 25 measurements. For iodometric titration, the same computations were used to determine the within-

assay, among-assay, and total assay imprecision, except that the number of replicates within one day and the number of days were three instead of five.

Because the WYD Iodine Checker can take multiple measurements from one preparation or vial (i.e., the sample solution vial contains 50 ml and the measurement cell for the WYD Iodine Checker holds approximately 4 ml), the within-vial imprecision was calculated. Five consecutive measurements from each vial of the 25 and 100 mg/kg iodate and iodide Morton Salt samples were taken. This assessed the instrument's reproducibility.

To assess the mixing accuracy (recovery) of the WYD Iodine Checker, we prepared a panel of eight salt samples containing different proportions of the noniodized, 25 and 100 mg/kg iodide or iodate Morton Salt samples (table 1). Three replicates from each of the prepared salt samples were measured. The averages of the three measurements were compared with the expected concentrations to determine the mixing accuracy of the WYD Iodine Checker for iodide and iodate samples.

The limit of detection for the WYD Iodine Checker was calculated by measuring 10 samples of noniodized Morton Salt. The samples were measured using the procedure for measuring iodide in salt. The mean plus three standard deviations of the 10 measurements indicated the limit of detection for the instrument.

A method comparison was performed between the WYD Iodine Checker and iodometric titration. Multiple measurements from the four Morton Salt samples containing iodide were conducted by both methods. A total of 47 salt samples fortified with  $\text{KIO}_3$  were measured by the WYD Iodine Checker and iodometric titration. These iodate salt samples included 4 Morton Salt samples and 43 market salt samples obtained from Argentina, Brazil, Chile, and Mexico. Since the two methods were run independently by two scientists, separate salt aliquots were used for each method. For future investigations, it is recommended instead to use subaliquots from the same salt aliquot once it has been dissolved for method comparison.

## Results and discussion

Table 2 presents imprecision data for the WYD Iodine Checker and iodometric titration using Morton Salt samples with concentrations of 25 and 100 mg/kg iodate and iodide. The total assay variability of the WYD Iodine Checker was approximately 9% when salt iodized with iodide was measured and 6% when salt iodized with iodate was measured (table 1). The total assay variability of the titration method was higher: about 12% to 14% for salt iodized with iodide and about 7% to 12% for salt iodized with iodate. The

TABLE 1. Mixing accuracy (recovery) for the WYD Iodine Checker

No.	Ratio of proportions: sample 1 + sample 2	Amount of sample 1 (25 mg/kg KI or $\text{KIO}_3$ )	Amount of sample 2	Expected concentration (mg/kg)	Average measured concentration (mg/kg)	Mixing accuracy (%)
<b>KI</b>						
1	1 + 4	5 g	20 g noniodized salt	5.0	6.2	124.0
2	1 + 2	5 g	10 g noniodized salt	8.3	10.8	130.5
3	1 + 1	20 g	20 g noniodized salt	12.5	14.8	118.4
4	2 + 1	30 g	15 g noniodized salt	16.7	17.8	106.4
5	4 + 1	40 g	10 g noniodized salt	20.0	21.6	108.2
6	2 + 1	30 g	15 g 100 mg/kg KI	50.0	50.0	100.1
7	1 + 1	20 g	20 g 100 mg/kg KI	62.5	58.3	93.3
8	1 + 2	15 g	30 g 100 mg/kg KI	75.0	70.1	93.5
Average						109.3 ± 13.9 (SD)
<b><math>\text{KIO}_3</math></b>						
1	1 + 4	5 g	20 g noniodized salt	5.0	5.0	100.7
2	1 + 2	5 g	10 g noniodized salt	8.3	8.6	104.0
3	1 + 1	20 g	20 g noniodized salt	12.5	12.6	100.5
4	2 + 1	30 g	15 g noniodized salt	16.7	16.5	98.8
5	4 + 1	40 g	10 g noniodized salt	20.0	19.9	99.7
6	2 + 1	30 g	15 g 100 mg/kg $\text{KIO}_3$	50.0	45.6	91.1
7	1 + 1	20 g	20 g 100 mg/kg $\text{KIO}_3$	62.5	51.9	83.1
8	1 + 2	15 g	30 g 100 mg/kg $\text{KIO}_3$	75.0	66.7	89.0
Average						95.9 ± 7.2 (SD)

TABLE 2. Assay imprecision for the WYD Iodine Checker and iodometric titration

Method	Mean and imprecision			
	Mean (mg/kg)	Total assay <sup>a</sup> CV (%)	Among-assay <sup>b</sup> CV (%)	Within-assay <sup>c</sup> CV (%) range
WYD (5 replicates/day, over 5 days)				
25 mg/kg KI	26.0	8.9	7.1	2.4–11.7
100 mg/kg KI	110.0	8.7	6.9	3.8–11.4
25 mg/kg KIO <sub>3</sub>	25.0	5.8	4.7	3.2–5.4
100 mg/kg KIO <sub>3</sub>	105.0	5.8	3.4	2.1–10.3
Titration (3 replicates/day, over 3 days)				
25 mg/kg KI	26.8	11.5	11.7	2.5–8.8
100 mg/kg KI	118.8	13.9	5.0	3.0–20.9
25 mg/kg KIO <sub>3</sub>	28.6	12.4	1.8	4.0–13.9
100 mg/kg KIO <sub>3</sub>	114.1	7.2	7.6	2.0–3.8

CV, Coefficient of variation

a. Standard deviation (SD) of all measurements divided by the grand mean of all measurements.

b. SD from the mean result of each day divided by the average of the mean results of each day.

c. SD of the results measured on the same day divided by the mean of results for that day; range reflects variability of the within-assay CV from day to day.

among-assay imprecision for salt fortified with iodide was 6.9% to 7.1% with the WYD Iodine Checker versus 5.0% to 11.7% with iodometric titration. For salt with iodate, the among-assay imprecision was 3.4% to 4.7% with the WYD Iodine Checker and 1.8% to 7.6% with iodometric titration.

The average within-assay imprecision for the WYD Iodine Checker was 5.8% (range, 2.4%–11.7%) when measuring salt iodized with iodide and 4.4% (range, 2.1%–10.3%) when measuring salt iodized with iodate. In comparison, the average within-assay imprecision for titration was 9.4% (range, 2.5%–20.9%) for salt iodized with iodide and 4.9% (range, 2.0%–13.9%) for salt iodized with iodate (table 2). The results of precision testing for the iodate and iodide Morton Salt samples indicated improved or comparable total assay and within- and among-assay precision for the WYD Iodine Checker versus iodometric titration. Less subjectivity associated with the WYD Iodine Checker compared with titration (i.e., reading the result directly from the instrument's display versus noting the color change of the sample) may contribute to the improved precision of the WYD Iodine Checker.

The average within-vial imprecision for the WYD Iodine Checker was 0.7% (range, 0.2%–1.1%) for the iodide samples and 1.2% (range, 0.0%–1.8%) for the iodate samples. This very low within-vial imprecision indicated the excellent reproducibility of measurements by the WYD Iodine Checker and suggested that one measurement from each prepared salt sample is fully adequate.

The mean recoveries for a panel of eight iodide and iodate salt samples obtained through proportional mixing were  $109.3\% \pm 13.9\%$  and  $95.9\% \pm 7.2\%$ ,

respectively, and thus fell in the suggested range of 85% to 115% (table 1) [1]. To visualize the results from this mixing accuracy test, we plotted the expected concentration versus obtained concentration (fig. 1): obtained iodate concentration =  $0.848 \times$  expected iodate concentration + 1.854,  $r^2 = .996$ ; obtained iodide concentration =  $0.901 \times$  expected iodide concentration + 3.060,  $r^2 = .998$ . The excellent correlations between the expected and obtained concentrations verified the high accuracy of the WYD Iodine Checker in detecting all iodine present in both iodate and iodide salt samples.

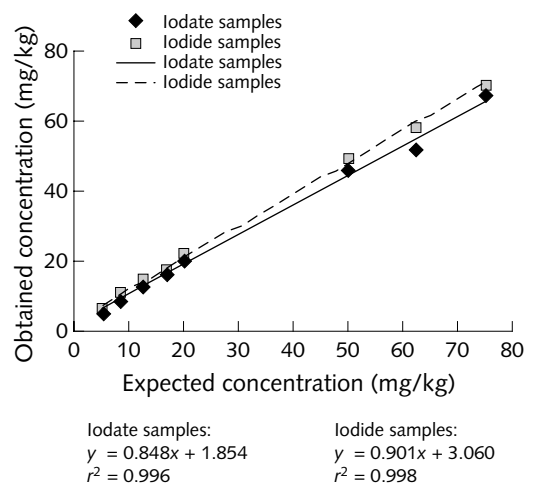


FIG. 1. Comparison of expected and obtained concentrations in a panel of eight iodide and iodate salt samples as measured by the WYD Iodine Checker in a mixing accuracy (recovery) test

The limit of detection of the WYD Iodine Checker was determined by 10 replicate measurements of the noniodized Morton Salt sample. One measurement of 5.5 mg/kg exceeded two standard deviations from the mean of the samples, and therefore it was confirmed as an outlier and rejected from the calculations. The mean of the nine remaining measurements was 0.43 mg/kg, with a standard deviation of 0.47 mg/kg. Therefore, the limit of detection of the WYD Iodine Checker was 1.84 mg/kg. This low limit of detection indicated that the instrument can detect very low levels of iodine. The outlier illustrated the necessity of taking proper precautions against contamination. Preventing contamination of the sample was most critical during the sample preparation process, because contamination was most likely to occur during this process. Precautionary steps such as the maintenance of a clean laboratory environment (e.g., the use of distilled water, clean spatulas, and 50-ml sample vials) and proper equipment maintenance (e.g., clean cell holders) can help prevent contamination problems.

Using the eight samples of Morton Salt with known concentrations of iodide or iodate (25, 50, 75, and 100 mg/kg), we compared the results obtained by the WYD Iodine Checker and iodometric titration (figs. 2 and 3). Multiple measurements of all samples were performed, and the error bars in figures 2 and 3 represent the mean  $\pm 1$  SD for each concentration. For salt samples fortified with iodide, we obtained a regression equation of WYD Iodine Checker =  $0.935 * \text{titration} - 2.458$ ,  $r^2 = .989$  (fig. 2). For salt samples fortified with iodate, we obtained a regression equation of WYD Iodine Checker =  $0.963 * \text{titration} - 3.659$ ,  $r^2 = .993$  (fig. 3). These results show that when fine, homogeneous salt is used, a very good correlation is obtained between the two methods. As shown earlier in the precision calculations, the WYD Iodine Checker reported less variability from multiple measurements than titration. The lower variability was particularly notable for the 100 mg/kg iodide salt sample, where the standard deviation for the WYD Iodine Checker (9.5) was more than half the standard deviation for the iodometric titration (16.5).

Comparison of all iodate salt samples ( $n = 47$ ; 43 market samples and 4 Morton Salt samples) measured by iodometric titration and the WYD Iodine Checker yielded a regression equation of WYD Iodine Checker =  $1.112 * \text{titration} - 1.113$ , with a slightly lower correlation coefficient ( $r^2 = .850$ ) than for the Morton Salt samples (fig. 4). This somewhat lower correlation might be a consequence not of the methods, but of varying iodine concentrations within the market salt samples. Some of the market samples measured in replicates displayed large standard deviations and broad ranges (table 3). This level of variation did not occur among the Morton Salt samples. Therefore, the iodine concentrations of these market samples may have varied because of the uneven distribution of iodine

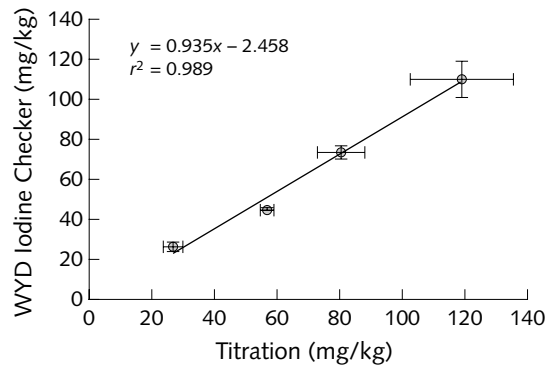


FIG. 2. Comparison of results obtained for four Morton Salt samples fortified with iodide as measured by titration and the WYD Iodine Checker

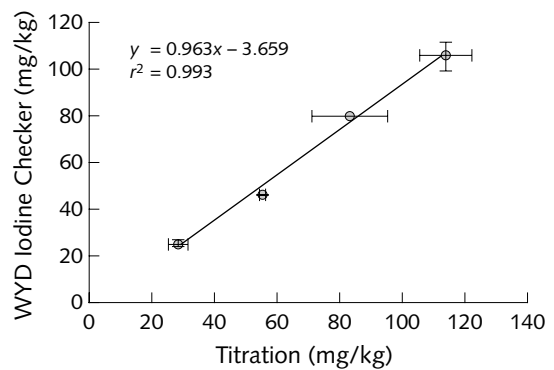


FIG. 3. Comparison of results obtained for four Morton Salt samples fortified with iodate as measured by titration and the WYD Iodine Checker

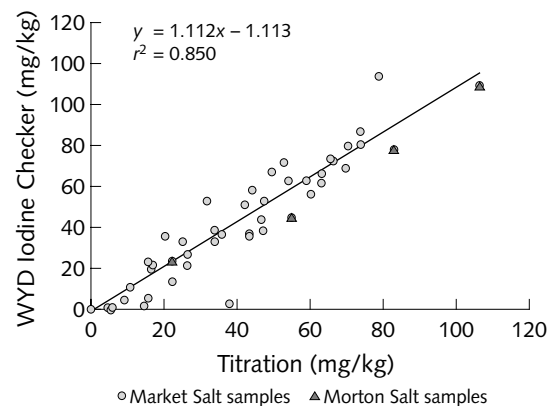


FIG. 4. Linear regression analysis to compare results obtained for iodate salt sample (43 market samples and four Morton Salt samples) as measured by iodometric titration and the WYD Iodine Checker

within the bags. A lack of homogeneity within bags of salt is reported to be a product of poor mixing at the production level [5].

The variation in the measurements of the iodate salt



TABLE 3. Comparison of results obtained for iodate salt samples as measured by iodometric titration and the WYD Iodine Checker

No.	Titration			WYD Iodine Checker		
	<i>n</i>	Mean $\pm$ SD (mg/kg)	Range (mg/kg)	<i>n</i>	Mean $\pm$ SD (mg/kg)	Range (mg/kg)
1	12	28.6 $\pm$ 3.2	22.2–31.7	25	25.15 $\pm$ 1.3	23.1–27.9
2	3	55.2 $\pm$ 1.1	54.0–56.1	2	45.9 $\pm$ 0.1	45.8–46.0
3	3	83.2 $\pm$ 12.2	76.2–97.3	2	79.7 $\pm$ 0.4	79.4–79.9
4	9	114.1 $\pm$ 8.2	102.6–129.96	25	105.3 $\pm$ 6.3	91.9–114.7
17	2	78.9 $\pm$ 6.7	74.1–83.6	4	116.4 $\pm$ 34.1	92.2–166.7
24	2	16.4 $\pm$ 14.3	6.3–26.5	5	19.9 $\pm$ 16.7	0.8–45.5
26	2	43.4 $\pm$ 1.5	42.3–44.4	2	36.5 $\pm$ 2.1	35.0–38.0
29	2	20.3 $\pm$ 23.6	3.6–37.0	4	36.4 $\pm$ 9.9	28.4–49.2
30	2	13.3 $\pm$ 3.7	10.6–15.9	3	44.8 $\pm$ 20.7	27.0–67.5
31	2	22.3 $\pm$ 1.5	21.2–23.3	4	14.1 $\pm$ 7.3	5.0–20.5
32	2	47.1 $\pm$ 12.7	38.1–56.1	4	39.2 $\pm$ 37.8	14.7–95.5
33	2	33.9 $\pm$ 10.5	26.5–42.3	4	39.5 $\pm$ 17.3	17.4–56.1
34	2	38.1 $\pm$ 20.9	23.3–52.9	4	2.8 $\pm$ 1.6	0.9–4.5
35	2	4.8 $\pm$ 2.2	3.2–6.3	4	0.6 $\pm$ 0.1	0.5–0.7
36	2	31.8 $\pm$ 14.9	21.2–42.3	4	54.2 $\pm$ 14.6	39.1–72.9
37	2	5.9 $\pm$ 3.7	3.2–8.5	4	0.6 $\pm$ 0.2	0.5–0.9
38	2	43.4 $\pm$ 3.0	41.3–45.5	4	37.6 $\pm$ 9.7	30.6–52
39	2	14.3 $\pm$ 9.8	7.4–21.2	2	2.0 $\pm$ 0.6	1.5–2.4
40	2	9.0 $\pm$ 3.7	6.3–11.6	2	4.7 $\pm$ 3.4	2.3–7.1

samples was also hypothesized to be greater with the WYD Iodine Checker than with titration because the WYD Iodine Checker requires 1 g of salt for analysis, versus 10 g for titration. If the iodate was not uniformly distributed within the bag, the smaller amount of sample required for analysis by the WYD Iodine Checker increased the probability of variation among multiple analyses of the same iodate salt sample. To minimize the potential for variation when using the WYD Iodine Checker, 10 g of the salt sample should be diluted in a 50-ml vial. From the 50-ml vial, 1 ml is then used for analysis following the WYD Iodine Checker instructions.

We illustrated the bias between the two methods by plotting for each iodate salt sample ( $n = 47$ ) the mean of the results ( $x$  axis) and the difference between the results of the two methods ( $y$  axis) (fig. 5). The mean difference was 3.4 mg/kg; however, this was a statistically nonsignificant bias (95% confidence interval,  $-0.06$  to  $6.94$ ). This means that bias-free agreement existed between the two methods. The central 0.95 interval (mean difference  $\pm$  2SD) indicated that 95% of the determinations by the WYD Iodine Checker were 20.55 mg/kg lower to 27.43 mg/kg higher than the concentrations determined by iodometric titration. We detected slight concentration dependency of the difference between the two methods ( $y = 0.195x - 4.803$ ,  $r^2 = .192$ ), with the difference increasing with increasing iodate concentration of the salt.

Important final discussion points regard the ease of use, cost, safety considerations, and field applicability

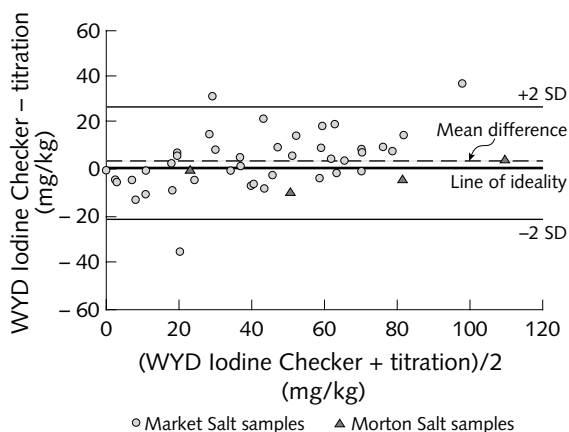


FIG. 5. Bland-Altman bias analysis to compare the difference between the WYD Iodine Checker and iodometric titration for iodate salt samples (43 market samples and four Morton Salt samples)

of the WYD Iodine Checker. The laboratory worker operating the WYD Iodine Checker in this study was a nonchemist with minimal experience preparing salt samples for analysis. The nonchemist worked with a chemist who prepared the solutions (e.g., standards, bromine solution, and sodium formate solution) required for the salt sample testing. The nonchemist reported the WYD Iodine Checker to be easy to operate, given the relatively simple sample preparation process and straightforward use of the instrument.

The WYD Iodine Checker kit costs approximately US\$360 and is equipped with 100 ml each of solutions A and B. The cost of the burette and burette stand needed for titration is roughly US\$260. When the supply costs required for both methods are calculated, the titration costs per sample are estimated to be US\$1.50, compared with just over US\$1 per sample with the use of the WYD Iodine Checker. The cost of the reagents used per sample is similar for both methods: US\$0.06 for titration and US\$0.07 for the WYD Iodine Checker.

Preparation of the solutions necessary for salt testing by the WYD Iodine Checker introduced important safety concerns and limitations in the field applicability of the instrument. Bromine solution, which is used for testing iodide salt, should be handled with caution and stored in a chemical fume hood. The safety concerns associated with handling bromine solution limit the field applicability of the instrument for measuring salt fortified with iodide. Second, in preparing the sulfuric acid solution or solution B, the acid must be added to the water slowly. Neither precaution is specified in the WYD Iodine Checker Manual, but both are significant safety concerns.

The 100 ml each of solutions A and B included in the WYD Iodine Checker kit can test about 45 to 48 samples. A chemist should prepare these solutions, plus the iodine working standard solution, bromine solution, and sodium formate solution when necessary. If only iodate salt is measured, the WYD Iodine Checker could be a useful tool for the field monitoring of salt iodine levels. To prevent contamination problems and to ensure proper functioning of the instrument and other necessary equipment (e.g., analytical balance), the WYD Iodine Checker should remain in a central field location for salt sample testing. Assessment of the performance of the WYD Iodine Checker in field conditions warrants further investigation.

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## Conclusions

The WYD Iodine Checker achieved better total assay and among- and within-assay precision than iodometric titration. This improved precision, along with the very good mixing accuracy of the WYD Iodine Checker (i.e., the accuracy of the measurement when salt samples with different iodine concentrations are mixed in different proportions) and its low limit of detection, verified that the instrument is highly precise, accurate, and sensitive. The measurements by the WYD Iodine Checker correlated well with titration measurements when iodide and iodate Morton Salt samples were tested.

We found a somewhat lower, but still acceptable, correlation between the WYD Iodine Checker and titration when testing iodate market salt samples. This lower correlation may not result from the analytical methods but rather from a lack of homogeneity of the salt being measured and/or the amount of sample used for analysis. One recommendation to minimize error caused by poor homogeneity of the salt would be to sample 10 g instead of 1 g of salt when using the WYD Iodine Checker.

The safety issues and chemical training requirements for the WYD Iodine Checker limit the field applicability of the instrument, particularly for measuring salt with iodide. However, further testing should be done to evaluate the field applicability of the WYD Iodine Checker for measuring iodate salt. A nonchemist reported the WYD Iodine Checker to be a user-friendly instrument based on a simple methodology with clear instructions for the sample preparation and testing of salt samples. The WYD Iodine Checker is easier to use by personnel who are not highly technically trained and is slightly less time-consuming than the titration method. Evaluation of the WYD Iodine Checker by the CDC indicated that the instrument is an accurate and reliable tool for the quantitative monitoring of the iodine concentrations of iodide and iodate salt.

# Adding an oxidant increases the stability of iodine in iodized salt

Huimin Shi

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## Abstract

*It has been shown that moisture plays a critical role in the stability of iodine and that reducing agents in iodized salt reduce the stability of iodine. We question whether this is valid in all cases, and have found that the reducing agent may play a more important role than moisture in decreasing the stability of iodine.*

*We reviewed current methods to enhance iodine retention in iodized salt, and propose methods to produce stable iodized salt and to analyze its stability. Our experiments showed that when reducing impurities are removed, iodine remains stable in iodized salt, even when the salt is "wet."*

*We suggest that the stability of iodine in iodized salt can be improved by oxidizing iodized salt with sodium hypochloride, and that the iodine content of iodized salt, after heating at 120°C for one hour, can be used to reflect the quality of iodized salt. We have demonstrated that reducing agents play a critical role in the stability of iodine in iodized salt.*

*We have shown a method of purifying salt by removing reducing materials, which can be used to produce iodized salt with sufficient stability at lower cost. We also propose an analytical method to determine the stability of iodine in iodized salt. These methods could be further developed to achieve better accuracy, precision, and reliability and be applied to a greater variety of iodized salts.*

**Key words:** Iodine, iodized salt, sodium hypochloride, stability

## Introduction

Diosady et al. have suggested that moisture plays a critical role in the stability of iodine, writing that "potassium iodate ( $KIO_3$ ) can be reduced to elemental iodine by a variety of reducing agents in the salt" [and] "elemental iodine readily sublimates and is then rapidly lost to the atmosphere through diffusion" [1, 2]. We question whether this is valid in all cases, and in fact we have found that the reducing agent may play a more important role than moisture in decreasing the stability of iodine. Potassium iodate is known to be extremely stable at temperatures below 200°C without a reducing agent and will not decompose until the temperature reaches 500°C. Potassium iodate and its solutions are widely used as standard substances for many analyses. However, if there are reducing impurities in iodized salt, potassium iodate in iodinated salt will be reduced to iodine, and the iodine in iodized salt will be lost. Our experiments showed that when reducing impurities are removed, iodine remains stable in iodized salt, even when the salt is "wet." All samples used by Diosady [1] (including the Canadian reference sample) may contain different amounts of reducing agents, so moisture may play a greater role in decreasing the stability of iodine in their study cases.

Diosady also states that "salt purification is the best technical means of preventing iodine loss; however, this would be prohibitively expensive in the short term for many developing countries" [2]. The list of impurities includes carbonates, bicarbonates, total carbonates, calcium, magnesium, barium, potassium, iron, strontium, and sulfur [2]. The amounts of these impurities in the brine used to produce salt, especially calcium, magnesium, potassium, and sulfur, are relatively high. Purifying salt and removing these "impurities" would truly be prohibitively expensive for many developing countries. However, if our aim is only to retain iodine in iodized salt in the form of potassium iodate, the term impurities should be restricted to reducing agents, and salt purification means just the removal of those reduc-

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ing agents. The cost of salt purification would not then be prohibitively expensive.

We analyzed whether salt produced in developed countries contains reducing agents and whether it needs advanced purification. Although many developed countries chlorinate the brine used to produce salt to remove reducing materials (such as hydrogen sulfide) before vaporization, the reducing materials in brine may not be completely removed. During vaporization, the facilities must be kept in a nonoxidizing condition to prevent metal corrosion. To achieve this condition, some vaporizing processes (including those in Canada) introduce reducing materials (such as sodium sulfite) to feed brine to remove oxygen. Although the concentration of such reducing materials in feed brine is relatively low, the concentration in salt-brine slurry could be high as a result of recycling of the mother liquid. In this case, salt dewatered from the salt-brine slurry could contain a certain amount of reducing materials. This may be the reason that Canadian salt packed in low-density polyethylene film bags loses 22.7% of its iodine after 12 months at 40°C and 60% humidity.

Diosady also writes, “by packaging salt in an effective moisture barrier such as solid low-density polyethylene bags, iodine losses can be significantly reduced” [1]. This is true for some samples then tested, but there was still a great loss of iodine after 12 months of storage. In some samples, such as the Chinese salt tested by Diosady et al., the losses were even more significant. Because the losses of iodine in various iodized salts are obviously different, retaining the iodine involves more than improving the packaging and storage of iodized salt.

The article also mentions that “in order to make allowances for the probable losses of iodine, countries must determine iodine losses from local salt iodized under local conditions, as these will be greatly affected by salt source, quality and processing technology” [1]. However, iodine losses from local iodized salt under local conditions are difficult to determine. In developing countries, there are many plants producing iodized salt. Even at the same plant, the iodine losses of iodized salt differ according to when it was processed, although the storage conditions are the same. In some plants, for example, the concentration of sodium thiosulfate in the initial feed brine can be as low as 10 mg/L. As the brine is vaporized, the concentration of sodium thiosulfate in the resulting salt-brine slurry gradually rises to more than 1,500 mg/L. As time goes by, the salt dewatered from this salt-brine slurry contains more and more reducing material. As a result, iodine losses in iodized salt are usually inconsistent.

## Current methods of iodine retention

The following methods of enhancing iodine retention

in iodized salt are in current use.

*Enhanced packaging.* Enhanced packaging can significantly lessen iodine losses by reducing the moisture content of iodized salt and the permeation of gases in the period of storage. However, this method cannot prevent oxidation-reduction due to residual reducing materials in salt, which can generate significant iodine losses.

*Increasing alkalinity of salt.* Adding soda to iodized salt increases the pH and decreases  $[H^+]$ , thereby decreasing iodine losses. However, there are some problems associated with this method. First, wet salt with a large amount of soda solution is difficult to dry in a fluidized-bed drier due to the high content of water in wet salt. Second, the public may dislike such alkali salt. Third, the cost of this treatment is high.

*Heat-iodized salt.* Iodized salt that has been heated at high temperatures for several hours is stable. However, there are disadvantages. First, the iodate added to the salt is partially reduced and lost during the heating procedure. Therefore, the cost of iodizing the salt will rise. Second, heating iodized salt at high temperatures for several hours is difficult to achieve on an industrial production scale. Third, as the content of reducing materials in iodized salt varies, the amount of lost iodate, the necessary excess amount of iodate, and the content of iodate in iodized salt vary. Finally, the iodine lost in the production process might give rise to an increase in the content of reducing materials in salt slurry, which could in turn give rise to a vicious cycle of addition and loss.

*Production of salt with purified brine.* Using such purified salt would improve the stability of iodine. However, brine purification removes a relatively large amount of impurities, such as  $Ca^{+2}$ ,  $Mg^{+2}$ , and  $SO_4^{-2}$ , and is very costly. Therefore, according to Diosady [1], “it would not be technically or economically feasible in the short term in many developing countries.” In addition, the iodized salt is not completely stable, even when purified salt is used.

## Proposed processing and analytical methods

It is crucial to explore the processing methods used to produce iodized salt and the analytical methods used to determine the stability of iodine in iodized salt. The following are some suggestions.

### Purifying salt

To purify salt, an oxidant is added to wet salt to remove the reducing materials. Since the quantities of reducing materials in wet salt are less than those in brine or in salt-brine slurry, purifying salt is easier and less costly than purifying brine. Removal of reducing materials by

this method is more efficient than removal by the use of purified brine.

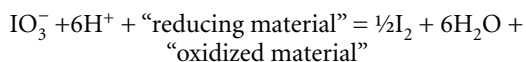
### Analytical method

Ten grams of iodized salt is placed in a 200-ml flask and heated in an oven at 120°C for one hour, and then is analyzed by titration. The iodine content of the salt is referred to as the MCIS (minimum content of iodate in iodized salt). The quantity of iodine lost after heating (L value) is regarded as the content of reducing materials in the iodized salt. We propose that the L value and the MCIS value be used to reflect the quality of this iodized salt. The MCIS value, especially, can be used as the stability index of iodized salt. Although there are many suppositions in this method, the quality and stability of iodized salt can be at least partly evaluated.

To show that the reducing agent plays a critical role in the stability of iodine, and to examine the suggestions given above, we performed the experiments described below.

### Background of the experiments

The reaction that gives rise to the iodine losses from iodized salt is an oxidation-reduction reaction, expressed as:



Since the velocity of an oxidation-reduction reaction is relatively lower than the diffusive velocity of iodine vapor, this reaction is a control reaction for the velocity of iodine losses from iodized salt.

The oxidation potential of potassium iodate would be  $E(V)$ .

$$E = 1.2 + 3.22 \times 10^{-5} \times T \times \log([\text{IO}_3^-][\text{H}^+]^6[\text{I}_2]^{-1/2})$$

$E$  is a function of  $[\text{IO}_3^-]$ ,  $[\text{H}^+]$ , and  $[\text{I}_2]$ . The higher the  $[\text{H}^+]$ , the larger the  $E$  will be.

Reducing materials include all materials (such as  $\text{Fe}^{+2}$ ,  $\text{I}^-$ ,  $\text{Br}^-$ ,  $\text{S}^{-2}$ ,  $\text{S}_2\text{O}_3^{-2}$ ,  $\text{SO}_3^{-2}$ ,  $\text{S}_2\text{O}_4^{-2}$ , and organic compounds) with oxidation potentials lower than the above-mentioned  $E$ . Therefore, the term “reducing material” refers to all materials that can reduce iodate in iodized salt to iodine rather than some specific substances. Since  $E$  is a function of  $[\text{IO}_3^-]$  and  $[\text{H}^+]$  in iodized salt, the quantity of reducing materials in iodized salt changes with  $[\text{IO}_3^-]$  and  $[\text{H}^+]$  in iodized salt. In this case, we would like to work out some analytical methods and special indices, like COD (chemical oxygen demand) in water analysis, to show the quantities of reducing material, and to show the minimum content of iodate in iodized salt stored in certain conditions for several months. Let us suppose that we can, and use the MCIS index to reflect and manage the

quality of iodized salt.

When the reducing material is added to iodized salt, the reaction velocity is a function of  $[\text{IO}_3^-]$  and  $[\text{H}^+]$ , as well as the temperature at which the iodized salt is stored. According to chemical kinetics, a reaction between ions in solution is quicker than one in the solid phase. As a result, the higher the moisture content of iodized salt, the quicker the reaction is. The higher the  $[\text{H}^+]$  of iodized salt (i.e., the lower the pH), the more iodine will be lost. Diosady noted, however, that “the effect of pH was also not clear-cut” [1]. The pH of salt was determined by these researchers at a time when the samples were received but not after the samples had been stored. The pH of the salt had continuously changed during the period of storage due to absorption of gases such as  $\text{CO}_2$  and  $\text{SO}_2$ . Second, they compared the effects of pH among different samples rather than within the same sample. Third, the pH they found was in the range between 6.25 and 9.77, but not higher.

The higher the temperature, the quicker the reaction. This kind of oxidation-reduction reaction would supposedly have a reaction velocity thousands of times faster at higher temperatures, for instance 120°C, compared with a reaction at ambient temperature.

### Materials and methods

The materials (salt, potassium iodate, sodium hypochlorite solution, and potassium ferrocyanide) used in our study were all of industrial grade.

Iodized salt, from which reducing materials had been removed by adding oxidants, was stored for 1, 2, 3, 6, 10, 12, and 18 months. The iodine content in these samples was then analyzed to determine whether the reducing agent played a critical role in the stability of iodine. The experiments on the removal of reducing materials in iodized salt were performed at industrial production scale (160,000 tons of salt per year), and the chemical analyses for iodized salt were performed according to GB/13025.3-91, GB/13025.4-91, GB/13025.5-91, GB/13025.6-91, GB/13025.7-91, and GB/13025.8-91 [3]. The sodium hypochlorite solution was analyzed by the titrimetric method (iodimetric analysis and alkalimetric analysis).

## Results

### Experiments using the analytical method

Samples taken from several plants were heated in a controlled-temperature oven at 120°C for one hour. The iodine in these samples, before and after heating, was determined by titration. The potassium iodate content is shown in table 1.

It is clear from these data that there were some losses of iodine during heating, and heating can be used to

TABLE 1. Potassium iodate content of iodized salt from several plants, before and after heating

Measurement	Plant no.					
	1	2	3	4	5	6
KIO <sub>3</sub> (mg/kg) before heating	65.3	20.2	57.6	31.2	38.2	40.0
KIO <sub>3</sub> (mg/kg) after heating (MCIS <sup>a</sup> )	59.8	13.2	36.7	29.7	34.5	26.1
Loss (%)	8.4	35	36	4.7	9.6	35

a. MCIS, Minimum content of iodate in iodized salt.

show the stability of iodized salt.

### Experiments in removing reducing materials in iodized salt

We used a sodium hypochlorite solution as our oxidant and used the following procedure:

wet salt (from centrifuge) → addition of sodium hypochlorite solution by spraying on transfer belt → mixing → drying in fluidized-bed drier → addition of potassium iodate solution and potassium ferrocyanide by spraying on transfer belt → mixing and transfer to salt storehouse with transfer belt → packing

In our first experiment, we added 84 L of sodium hypochlorite solution (NaOCl 110 g/L, NaOH 20 g/L) to 151.7 ton of salt. This is equal to 0.557 L (0.061 kg) of sodium hypochlorite per ton of salt. The salt produced was packed in polyethylene bags. Two bags of salt (about 15 kg), with different amounts of KIO<sub>3</sub> added and poorly sealed, were stored in a humid place near a water pool in our laboratory. Analyses were performed on those samples; the results are shown in table 2.

When exposed to intense humidity, the salt in the bags gradually changed, but it can be seen from these data that the iodized salt sprayed with sodium hypochlorite solution was relatively stable. Although the exact moisture content of the salt was not determined, the surface of the salt was wet to the touch, suggesting that moisture does not play a critical role in the stability of iodine in this case. The MCIS values were never higher than the potassium iodate content of

iodized salt, even after 18 months of storage. Therefore, that MCIS value might be used to reflect the quality of iodized salt.

In our second experiment, we added sodium hypochlorite solution (NaOCl 121.5 g/L, NaOH 8 g/L) to wet salt. This was equal to 0.557 L (0.068 kg) of sodium hypochlorite per ton of salt. The cost of this oxidant is extremely low (less than US\$0.04 per ton of salt). The salt produced was packed in polyethylene bags (50 kg per bag). The bags were adequately sealed and stored six bags high and six bags across in a common salt storehouse (table 3).

The content of these iodized salts was NaCl 99.49%, H<sub>2</sub>O 0.25%, insoluble in water 0.2%, CaSO<sub>4</sub> 0.12%, CaCl<sub>2</sub> 0.05%, and MgCl<sub>2</sub> 0.03%.

As mentioned earlier, iodized salt sprayed with sodium hypochlorite solution is relatively stable. Thus, we confirmed that a reducing agent plays a critical role in the stability of iodine. The amount of sodium hypochlorite added in our experiments was about three times the amount that was theoretically necessary to remove the reducing materials. The excess sodium hypochlorite fully decomposed, and the resulting oxygen was blown out in a fluidized-bed dryer at an elevated temperature (120°C) for about 6 minutes. The temperature of dried salt at the outlet of the dryer was about 50°–60°C. The odor of the processed salt, which is similar to the odor of bleach powder, fully disappeared while the salt was packed.

### Conclusions

We have demonstrated that reducing agents play a critical role in the stability of iodine in iodized salt. We have shown a method of purifying salt by removing reducing materials, which can be used to produce iodized salt with sufficient stability at lower cost. We have also

TABLE 3. Stability of iodine in iodized salt, oxidated with sodium hypochloride in the second experiment

Original KIO <sub>3</sub> (mg/kg)	KIO <sub>3</sub> (mg/kg) after storage		
	1 mo	6 mo	12 mo
101.5	103.6	96	116.3

TABLE 2. Stability of iodine in iodized salt, oxidated with sodium hypochloride in the first experiment

Bag no.	Original KIO <sub>3</sub> (mg/kg)		KIO <sub>3</sub> (mg/kg) after storage					
	Unheated	Heated 1 h at 120°C (MCIS <sup>a</sup> )	1 mo	2 mo	3 mo	6 mo	10 mo	18 mo
1	53.8	52.1		54.5		54		
2	26.4	25.3	26.7		28.1		27.4	27.3

a. MCIS, Minimum content of iodate in iodized salt.

proposed an analytical method to determine the stability of iodine in iodized salt. These methods could be further developed to achieve better accuracy, precision,

and reliability and could be applied to a greater variety of iodized salts.

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## Commentary on "Adding an oxidant increases the stability of iodine in iodized salt"

The author makes the important point that humidity by itself is not an independent causal factor in the reduction of iodine content in iodized salt. This offers an explanation of why better packaging does not necessarily prevent the effect of humidity when reducing agents are present.

We know from work in the 1950s at the Institute of Nutrition of Central America and Panama (INCAP) that iodate is more stable than iodide [1]. The oxidation-reduction reaction of iodide is much quicker than that of iodate. This has been the basis for recommending the use of iodate in hot and humid climates. However, even when iodate is used for salt iodization, some decomposition to elemental iodine happens in the presence of reducing agents. At a given concentration of reducing agents, the reaction is quicker at lower pH (higher  $H^+$  concentration) and in the presence of humidity.

Regarding the practical implications of using NaOCl/NaOH as proposed by the author, there are two things to note. Heating and drying the salt at 120°C after treatment needs evaluation as to its cost and the organoleptics of the end product; moreover, the use of the oxidant NaOCl will influence the titration value of iodine. To assure the stability of iodized salt, therefore, it is most important that the amount of reducing agents be minimized. When reducing agents are present in salt, the second consideration for stability is the pH ( $H^+$  concentration) and humidity. A low pH and a relative humidity above 75% promote the reaction.

The practical relevance of these factors to the stability of iodate in iodized salt therefore depends on the source of the salt, the production method, or both.

**Sea salt.** Sea or solar salt normally has a pH close to neutral but is high in organic and chemical impurities. Additives are not always used in its production; when

they are used, anticaking or free-flow agents are more usual. Sea salt is comparatively humid when dispatched (even when bagged in polyethylene). In terms of iodine stability, iodized sea salt is often the least stable among the various types of salt produced in the world.

**Evaporated salt.** Without prior brine purification, evaporated salt normally also has a pH close to neutral, but it has many impurities, mostly chemical. This salt is more expensive to manufacture than sea salt. Additives, such as anticaking agents, are often used. This is the most common type of salt produced in China. In China, many brine sources are high in sulfide ("black brine"), which accelerates the decomposition of iodate, as indicated by the author. The author proposes research to establish the value and feasibility of adding an oxidant plus raising the pH. He proposes a hypochlorite/sodium hydroxide solution. These chemicals are cheap, but the economics of managing this extra step must be considered too.

**Evaporated (rock) salt after purification of brine.** The evaporated salt produced from purified brine (PVD, or pure vacuum-dried salt) is still more expensive. PVD salt has a high pH (alkaline: thus a low  $H^+$  concentration) and hardly any impurities, and anticaking agents are usually added. This would seem the type of salt in which iodate is stable (this is the type that was used when salt iodization started with iodide in the West).

Most of the world consumes salt other than PVD, and we cannot wait to eliminate iodine deficiency until PVD salt is provided to and accessed by all, which makes the proposed research important. We need to know more about the removal of reducing agents and its potential in fine-tuning recommended levels of iodate in consumption salt as well as potential savings in its manufacture.

The author also proposes the MCIS (minimum content of iodate in iodized salt) criterion as a normative index for defining the “true” iodine content of iodized salt. Again, this would be most relevant for non-PVD salt (see above). For quality assurance by producers and for food inspection at production, the MCIS might be less subjective than the present titration results in the absence of further chemical information, such as reducing agents, pH, and humidity. Again, more data on different salt sources and types are needed.

In summary, the author’s observations on stabil-

ity are relevant for the usual situation in most of the world, where large populations depend on the salt supply from the sea or from underground sources with simple evaporation.

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# Biocultural diversity in the sustainability of developing-country food systems

Timothy Johns and Bhuwon R. Sthapit

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## Abstract

*The policy implications of a model of contemporary food systems for developing countries that integrates nutrition, reduction of disease risk, culture, income generation, and biodiversity are reviewed within a theoretical and empirical examination of the relevance of nutrition to the priorities put forward at the World Summit on Sustainable Development in Johannesburg, South Africa, 2002. Agricultural, health, economic, and social policies with local reach are necessary responses to the increase in noncommunicable disease associated with the globalization of food systems. Nutrition offers a nexus for the changes in individual behavior and motivation essential for fundamental shifts in production and consumption patterns. Mutual consideration of biocultural diversity and nutrition can guide policy, research, promotion, and applied action in developing countries. Benefits from enhanced use of biodiversity must legitimately flow to the undernourished poor, while potential negative consequences must be minimized and mitigated. Quality and quantity of food need not be mutually exclusive. Functions related to energy density, glycemic control, oxidative stress, and immunostimulation define important research priorities. Tests of the hypothesis that biodiversity equates with dietary diversity and health might combine quantitative indicators of dietary and biological diversity with nutrition and health outcomes. Biodiversity, where it is*

*part of traditional agricultural and food systems, can be best conserved and enhanced through rational use within a broad-based developmental focus on small-scale and low-input production. The fact that traditional systems, once lost, are hard to recreate underlines the imperative for timely documentation, compilation, and dissemination of eroding knowledge of biodiversity and the use of food culture for promoting positive behaviors.*

**Key words:** Agro-biodiversity, dietary diversity, functional food, nutrition transition, wild food, WSSD

## Introduction

Antecedents to profound dietary changes that are rapidly redefining nutrition and health priorities in developing countries parallel those that constrain environmental sustainability. Healthy diets for populations depend on availability and accessibility, within a context that promotes and supports healthy behaviors, of a variety of plant and animal foods. Although both these resources and positive behaviors are characteristic of traditional food systems, contemporary trends simultaneously erode biodiversity and the sociocultural context in which it is conserved.\*

Nutrition policies, research, and applications should be guided by concerns for sustainable development. The World Summit on Sustainable Development (WSSD) in Johannesburg, South Africa, 2002, re-established and extended a steep challenge to the international community [3]. Specifically, its Plan of Implementation calls for the promotion of three interdependent and mutually reinforcing pillars of sustainable development: economic development, social development,

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\* *Biocultural* emerges conceptually from an anthropological consideration of the manner in which human societies adapt to the varied biological circumstances in which they live. *Biocultural diversity* is concerned with the relationships among traditional knowledge, biological diversity, and cultural diversity [1, 2].

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and environmental protection. In seeking to define tangible and relevant approaches to global problems it put forward five key focal areas—water, energy, health, agriculture, and biodiversity (WEHAB)—with an accompanying call to pursue the interrelatedness among these themes [4] along the lines put forward in the Indaba Declaration on Food, Nutrition, Health and Sustainable Development from the WSSD Implementation Conference, 2002 [5]. Nutrition, being intrinsically multidisciplinary, offers timely heuristic lessons for making the concerns of WEHAB mutually reinforcing, as well as a strategic role in providing key linkages with the emerging Global Strategy on Diet, Physical Activity and Health [6]. For nutrition, linkages arise most naturally between health and agriculture, as well as in relation to water and sanitation.

The present review extends the interconnections, first with concern for the nutritional consequences of economic and environmental changes on food systems, and more amply in considering the importance of biodiversity for dietary diversity and health. Its focus is consistent with the insights and important contributions of food systems research and interventions linking nutrition and agriculture [7, 8], while extending an emphasis on biodiversity. It draws on evidence-based research and consolidates the few initiatives and contributions in the literature that are addressing these issues in theory and practice. In addition to presenting a theoretical and empirical basis for the increasing interconnection of nutrition and environmental considerations, this review identifies the policy implications of a desired model for improving contemporary

food systems by integrating nutrition, reduction of disease risk, culture, income generation, and biodiversity (fig. 1). International and national policies that build on the biodiversity and cultural strengths inherent in traditional food systems optimize the chances for vulnerable populations to adapt to changing conditions in a sustainable manner.

Forestalling the imminent extinction of up to one-quarter of the world's wild species and the loss of important agro-biodiversity, while at the same time assisting the 800 million undernourished humans and some 1.2 billion living in extreme poverty, sets a formidable task [9]. Simply feeding the world's growing population by 2030 brings a threat of large-scale natural destruction. Meanwhile, dietary patterns are changing, and obesity accelerates at unprecedented rates [10]. Solutions are neither obvious nor realistic when taken in isolation. A biodiversity-focused strategy therefore has relevance within a multipronged approach that includes improved and sustainable production technologies, changes in trade agreements and food-pricing policies [11], poverty reduction, education, and improved health care.

Fundamental changes in human behavior can be founded on economic incentives, health benefits, values, and knowledge. Although extensive diversity may not be necessary for humans to satisfy basic nutritional needs, within a sociocultural context traditional biodiversity use is a potentially powerful vehicle for maintaining and enhancing health-positive behaviors [12, 13]. Conversely, health and economic gain can be mutually reinforcing of biodiversity conservation, as



FIG. 1. Population-level synergies linking biodiversity conservation and human nutrition in developing countries

they provide the impetus for positive practices and sustainable development.

While formal declarations related to environment or nutrition acknowledge the other in condensed terms or development jargon codewords such as food security or health and sustainability, respectively [e.g., 14–16], the WSSD presents a new imperative to move beyond mutual deference. In retrospect, the World Declaration and Plan of Action for Nutrition (WDPAN) [17] is attentive to sustainability, with clear calls that improved nutrition and health should be founded on environmentally sound development, including the conservation and protection of biodiversity and traditional resources. Food-system approaches to nutrition also characteristically emphasize the sustainable use of resources [7]. More recent summits, symposia, and some intervention initiatives have taken up these themes [18].

## Contemporary changes in food systems

Forces of globalization, commercialization, population increase, and urbanization change patterns of production and consumption and profoundly affect human diets. High-input, high-yield agriculture and long-distance transport increase the availability and affordability of refined carbohydrates (wheat, rice, and sugar) and edible oils [6, 11, 19, 20]. While making greater numbers of people secure in terms of energy, they also underpin the so-called nutrition transition [10, 21] and can undermine the self-sufficiency and economic viability of local producers [11, 19]. India, for example, has in the last five years gone from self-sufficiency to being the world's largest importer of edible oils. At the same time as changing trade policies undermine the livelihoods of local farmers, health changes associated with changes in the Indian diet [22] are further exacerbated. Edible oils, imported rice, and wheat also replace traditional cereals as the main energy sources in African countries [23]. In Sub-Saharan Africa, importation of food has increased the yearly per capita consumption over the past 30 years by about 7 kg for rice and wheat and 2 kg for edible oil [20]. Among periurban populations of Dakar, Senegal, we observed in a recent survey that imported rice, wheat bread, and sugar accounted for the majority of calories in diets, with high rates of micronutrient deficiencies. Nonetheless, traditional millet foods, which account for only 12% of energy, remain the largest contributor of iron (providing 46% of the intake although bioavailability reduces the contribution).\* In addition, globalization of culture and commercial activities promulgate a westernization of developing-country food systems and diets [19]. For example, Bourne et al. report that in South Africa,

\*Spigelski, Johns, and Gray-Donald, unpublished results.

increased westernization of diets is occurring even in rural areas [24].

Such changes also profoundly affect local systems of production. Fewer farmers engage in subsistence agriculture in the classic sense. Most are increasingly oriented to markets for both income and food purchase [18, 24–26]. Market factors alter traditional cropping patterns and, in general, result in erosion of the agricultural biodiversity represented by traditional crops and varieties [19]. Commercialization can, however, provide opportunities through which biodiversity can be retained and enhanced, as has been documented in Vietnam [25]. In other contexts, home gardens that serve as important complementary resources for diet and medicine [27] as well as important repositories of biodiversity may assume less importance [25, 28, 29].

Commercial monocropping can offer economic benefits to rural populations and reduced food costs to consumers, but it has mixed impacts on nutritional status [30, 31], in part because of reduction in traditional dietary diversity [31]. Changes in land use, including disturbance, deforestation, and appropriation of natural areas, diminish opportunities for gathering and hunting the essential wild components of many traditional food systems [1, 32]. Contamination from industrial and agricultural activities further undermines traditional and indigenous food systems and health [32], while climatic change will probably adversely affect crop production and nutritional status, at least in Africa [18]. Growing pressure on water resources also directly affects productivity and food security [18].

Since most of the world's impoverished populations live in countries harboring the largest amounts of biodiversity, conservation and poverty cannot be addressed independently [4, 14]. Sustainable development thus requires coupling investment in rural enterprise and infrastructure with sound resource management. The model put forward here assumes in its simplest form that small-scale farmers can manage and use traditional agro- and wild biodiversity to comparative economic advantage on the premise that the products marketed are desired by, and offer nutritional and sociocultural benefits to (increasingly urban) consumers. Linking biodiversity and health is both a response to the consequences of economic growth and a way to direct growth in a positive manner.

## Diet-related trends in developing-country demographics and health

### Food insecurity and undernutrition

In the face of persistent food emergencies and the scale of global hunger, addressing nutrient deficiencies remains an immediate priority. Food deficit and low

dietary diversity in both animal and plant foods simultaneously characterize food inadequacy for the chronically undernourished [33], although the current low cost of staples relative to nonstaples means that diets can be simultaneously adequate in energy and deficient in micronutrients [34]. The fact that access to quality food is often a problem of affordability rather than availability underlines the fundamental importance of poverty alleviation. The fact that large-scale agriculture in India produces surpluses while 250 million rural farmers remain malnourished [18] suggests that advanced technology is not a complete solution. Unless policies and programs for food security approach food systems in holistic terms, they will exacerbate malnutrition and disease in the long term.

### Nutrition transition

Increasing numbers of the malnourished poor live in urban areas. Consumption of a diet derived from high-energy foods of plant and animal origin coincides with low energy expenditure. The greater diversity, including fruits and vegetables, generally available to urban populations does not necessarily translate into consumption [21], particularly for the poor. An increasing number of urban residents depend on “junk food” or street foods, which are too often fried foods of low nutrient density [33, 35, 36]. Processed foods available for purchase through contemporary market systems, while potentially variable in brand and formulation, may have limited actual biological diversity, often related to the use of imported replacements for local foods.

The nutrition transition is leading to emerging epidemics of type 2 diabetes mellitus, cardiovascular disease, obesity, cancer, and other chronic noncommunicable diseases, even within poor countries [6, 10, 21]. The consequences of a high-carbohydrate, high-fat diet are further complicated and compounded among the disadvantaged in developing countries, where dietary changes in combination with poverty and high rates of infectious disease and undernutrition create a double burden [10, 21].

In Latin America and elsewhere, cheap food energy combined with low diversity and nutritional quality produces a pattern of obesity, particularly of women, in combination with household undernutrition [34]. Early childhood malnutrition (fetal programming) probably increases susceptibility to diabetes and other conditions in later life [21]. Epidemics of chronic noncommunicable diseases can be expected to further accelerate in countries with aging populations.

### Promising models of food systems in transition

In the transition to lifestyles more characteristic of

Western industrial societies, countries that retain a strong traditional food system in which diet has recognized health, cultural, and ecological roles best avoid the often concomitant increases in chronic noncommunicable diseases [21]. Asian and Mediterranean diets [37] provide the clearest examples. Kim et al. [10, 38] offer sociocultural explanations for the lower than expected rates of chronic noncommunicable diseases in South Korea. The congruence of physiological, cultural and ecological function is well represented by the concept of *Sin-To-Bul-Yi* (“A body and a land are not two different things”). Strong social marketing emphasizes the higher quality of traditional dishes based on the interpretation that “a person should eat foods produced in the land where he or she was born and is living.” Okinawan food, which has been strongly influenced by Chinese ideas of longevity through traditional diet, offers a further example [39].

Traditional systems often see food, medicine, and health as interrelated [40, 41]. Food may have strong symbolic and religious value and is highly associated with cultural identity and social well-being [41]. The foods of indigenous peoples form part of rich knowledge systems [2]. They typically draw on indigenous resources, are based on local production, and are associated with the land and environments from which they are obtained. The merits of such concepts for guiding contemporary adaptation are testable in general terms, in the first instance in relation to scientific evidence for the health benefits of traditional food biodiversity, and second for their validity as a sociocultural basis for positive systems.

### Empirical base for risk-reduction potential of developing-country foods

The fact that traditional food systems provide the inspiration for seminal insights into the relationship of diet and health (for example, the importance of fiber, omega-3 fatty acids, and antioxidants in African, Inuit and Mediterranean, and Asian diets, respectively [42]) underlines the theoretical value of their investigation [43]. For societies in transition, diets characterized by indigenous cereals, legumes, and fruits and vegetables provide lower energy content and higher fiber than the staple commodities [39] and presumably reduce the risk of disease. In general, however, the evidence for the health benefits of traditional foods is circumstantial and is rarely based on randomized, double-blind clinical trials or epidemiological studies. In sum, the evidence is similar but marginally less than the body of data supporting the disease-risk-reduction values of foods generally [39]. Nonetheless, a number of dietary factors of potential importance for specific health conditions in a developing-country context can be considered.

### **Dietary diversity**

A handful of epidemiological studies underline the benefits of a varied diet, particularly one including fruits and vegetables, in increasing longevity and reducing the rates of chronic degenerative diseases [36, 44] and in improving nutritional quality and child growth in developing countries [36, 45–47]. The diversity of indigenous crops and wild plant and animal species available in most tropical countries, in addition to providing essential nutrients, presumably offers broad benefits to health [45, 46]. Considering the difficulty in precisely identifying optimal diets, a diverse and balanced diet, including legumes, fruits, vegetables, and animal-source foods, provides an intrinsic buffer against the uncertainties of change and remains the preferred choice for human health [48].

### **Nutritional value of traditional edible species and varieties**

Although wild and cultivated biodiversity in most developing regions is ignored in dietary surveys, compositional analyses, Food and Agriculture Organization food balance sheets, and policy and decision-making [49], such resources unquestionably make essential contributions to dietary adequacy [36, 50, 51]. Studies of home gardens have made the links between diversity and nutritional status [27, 36, 52]. In exceptional cases, the contribution of specific nutrients from gathered species has been clearly demonstrated [46, 53], while many indigenous species have exceptional nutritional properties [54].

Documentation of the contribution of intraspecific diversity to nutrition and health has received little attention and analytical resources. Farmer-based research demonstrates the wealth of traditional knowledge and beliefs concerning the health, sensory, and culinary properties of local crop varieties [55]. Screening of major crops [36, 52, 55, 56], while incomplete, clearly documents wide variation in nutritional and functional properties that undoubtedly has implications for the nutritional status of populations and individual consumers (in addition to its usefulness to plant breeders). The potential genetic variation in nutrient composition within neglected and underutilized species [50, 52, 57] has been even less documented.

### **Reduction of the risk of cardiovascular disease and diabetes**

The role of foods and food constituents such as soy protein, flaxseed, cereal fiber, plant sterols, omega-3 fatty acids, fish, and lycopene in reducing risk factors for cardiovascular disease [58] has implications for developing country diets. Less-studied and widely distributed foods, such as whole-grain cereals includ-

ing buckwheat [59], grain amaranth [60], and millet [61], various leafy vegetables [62], grain legumes [63], fermented foods, and foods high in antioxidants, offer similar potential as part of various traditional food systems.

Variation in the glycemic response to foods that comprise major portions of developing-country diets, including varieties of rice [64], finger millet [65], and buckwheat [59], has profound health implications. Soluble and insoluble fiber, digestibility-inhibiting phytochemicals in food, and the nature of particular carbohydrates improve glycemic control [66]. A number of foods contain compounds that directly affect insulin resistance, e.g., bitter melon and fenugreek [66]. High intake of fruits and leafy vegetables is associated with low glycosylation of hemoglobin and may contribute to the prevention of type 2 diabetes [67]. Common polyphenolics, such as the isoflavonoid genistein and curcumin, inhibit the formation of advanced glycation end-products [68], low-density lipoprotein peroxidation [68], and lens aldose reductase [69].

### **Blindness and vision impairment**

Ingestion of the xanthophyll carotenoids lutein and zeaxanthin, which comprise the major macular pigments, may reduce the risk of age-related macular degeneration and cataracts [71], the leading cause of blindness worldwide. The benefits of non-nutrient carotenoids in leafy vegetables, which represent rich biodiversity in African and many Asian food systems [50], may exceed those attributable to beta-carotene or other nutrients. For example, vegetable diets that make modest contributions to improving vitamin A status result in significant increases in serum levels of lutein [72]. Nigerian patients with cataracts had consistently lower intakes of fruits and vegetables than control subjects [73]. Even for xerophthalmia, food-based strategies that increase dietary variety offer benefits in directly increasing vitamin A intake and improving its utilization [74].

Lens aldose reductase inhibitors, which include the common flavonoid quercetin and other antioxidants, may mediate diabetes-related retinopathy [68]. Hyperinsulinemia may contribute to increasing rates of myopia and other diseases in populations with high consumption of rapidly digestible refined carbohydrates [75], an observation that suggests a mechanism through which dietary modification can mediate such conditions.

### **Communicable disease**

Probiotic [76], immune-stimulant [77], and antibiotic [36, 41] properties of traditional foods offer largely unexplored benefits in reducing diarrheal and other infectious diseases.

### Other potential functional properties

Similarly, insights into cancer risk reduction attributable to antioxidants, flavonoids, carotenoids, lutein, phytoestrogens, and cruciferous vegetables extrapolate to indigenous foods [78]. Within developing-country contexts, spices [79] and other foods may also offer specific anticancer benefits. A number of other functional properties, such as further antioxidant activities, cognitive improvement, antidepressant, and modulation of xenobiotic stress, demonstrate the largely unexplored potential benefits of traditional diets.

### Merging empirical evidence with sociocultural values in practice

Authentic global sustainability depends on a paradigm shift in human values and behavior leading to profound changes in production and consumption patterns [3]. Accordingly, the following disparate examples suggest the beginnings of a common coalescence in the way traditional culture can combine with empirical evidence to both meet human needs and increase the value of biodiversity. Extensive efforts and published works related to food-systems approaches over a number of years provide a conceptual and practical context for these and other initiatives [7, 8, 13, 23].

### Food-based dietary guidelines

Food-based dietary guidelines (FBDGs), as developed from the WDPAN and subsequent initiatives, emphasize the use of locally available foods, food variety, traditional cuisines, and culturally sensitive methodologies to address both undernutrition and the nutritional transition [80]. An evidence-based approach to nutrition and health function helps direct the production, preparation, processing, and development of foods. FBDGs serve as the basis of both public education and sound public policy.

In their most elaborated presentation, that for the Western Pacific Region [80], FBDGs identify the environmental contributions from promoting local and traditional foods as reduction in fossil energy use and pollution from long-distance transportation and intensive agriculture. Surprisingly, while extolling food variety, the discussion is silent on the benefits for enhancing biodiversity.

Lessons in synthesizing sociocultural values, economic development, and scientific research from the Asian regions [38, 39] where poverty has declined most significantly in the past 30 years offer potential guidance for countries, particularly in South Asia and Sub-Saharan Africa, where poverty and malnutrition have not declined.

### Nutrition of indigenous peoples and the environment

Both the WDPAN and the WSSD acknowledged the special case of indigenous peoples. The unique lifestyles, knowledge systems, and other means by which indigenous communities meet their nutritional needs offer extant and badly needed models of how humans can adapt using the local resources available in varied environments [32]. Indigenous communities are both sentinels of environmental distress and stewards of important biodiversity [81]. At the same time, they are among the most marginalized and impoverished in the contemporary world. As victims of sociopolitical factors outside their control, economic development, and environmental change, they are profoundly implicated in environmental issues and play important symbolic, political, ethical, and practical roles of leadership in the struggle for universal sustainability.

In consort with initiatives such as the Centre for Indigenous Peoples' Nutrition and Environment (CINE) (<http://cine.mcgill.ca>) [81], the IUNS Task Force on Indigenous Food Systems and Nutrition (<http://www.iuns.org/taskforces.htm>) [23], and others [82], indigenous communities engage in community-based scientific research to guide the course along which they can continue to meet their subsistence, economic, and social aspirations.

### On-farm conservation of agricultural biodiversity

In Nepal, community-based approaches to agro-biodiversity conservation promote the value of landraces through cultural linkages, market incentives, and health associations [83], while a project of the International Plant Genetic Resources Institute (IPGRI) on traditional leafy vegetables [50] is developing along similar lines in Sub-Saharan Africa.

### Functionality as a physiological, environmental, and philosophical construct

For developing countries, something approaching functionality is emerging de facto as communities around the world adapt traditional systems and values to modern socioeconomic situations, while synthesizing traditional knowledge with ideas drawn from the global information arena.

Food functionality as a contemporary concept embraces aspects of scientific research (and conjecture), changing consumer values, and entrepreneurial initiative [39, 84]. It likewise presents one step toward the change in consumption and production patterns in which the WSSD states developed countries, given their past records, must take a lead [3].

A desired outcome of reducing the risk of chronic noncommunicable diseases on the one hand, and issues

of production, marketing, and regulation on the other, define policy discussions of functional foods in developed and, to a growing degree, developing countries [85]. Nonetheless, philosophical and ethical considerations that embrace aspects of self-sufficiency, spirituality, nostalgia for the past, and environmentalism, as well as physical health (real or imagined), motivate consumers of functional foods and dietary supplements [84]. Organic foods, vegetarianism, and the resistance in some jurisdictions to genetically modified foods further illustrate the passions, perceptions, and misperceptions—with interesting links to sustainability—that food evokes. The actual products purchased are further influenced by promotions combining both health and environmental messages. The fact that countries with very distinct food cultures, such as Japan and the United States, embrace functionality suggests that the concept has broad cross-cultural transference.

Modern popular ideas parallel traditional concepts of health. Contemporary food can assume physiological, social, cultural, and ecological function without the need to express its role in such terms. Perhaps not surprisingly, consumers and marketers look to developing countries as sources of new functional foods and beverages [86].

In this context, personal health, being of more immediate self-interest to consumers than the health of remote systems of production, offers a useful entry point to sustainability. Set within a cultural context, a coupling of human health, ecosystem health, and shared values provides the beginnings of the paradigm shift that re-establishes the local and global links between production and consumption, and the interests of people of rich and poor countries alike.

### **Reconstructing sustainable food systems: policy and practice**

Developing countries are challenged to reconstruct their food systems in positive ways. They differ in their robustness to global commodities, economic forces, and westernization, depending on their needs and culture. For example, South Asia, Ethiopia, and the West African region have strong identifiable food traditions, while ethnic, economic, and historical factors may make those of other countries in Sub-Saharan Africa less cohesive. In any case, progressive nutrition and food policies can proactively integrate and direct the evolution of the food system in optimal ways.

Although professionals comprehend at least the nature of the changing demographic, dietary, and health realities of the developing world, redefining the priorities of institutions responsible for nutrition and food, health, agricultural, economic, and educational policies lags behind. Food security, as usually operationalized, prioritizes energy and micronutrient

requirements, issues that primarily draw on targeted, reductionist, and technological approaches to nutrition and health. Vested interests in the marketplace and economic structures further contribute to a focus on a limited diversity of staple crops.

Thus, most nutrition interventions address the symptoms of a problem, rather than the causal factors and the whole health or systematic contexts from which real and lasting solutions must come.

Novel and more sophisticated approaches to developing-country nutrition seem necessary and timely [87]. Efforts fostered by private or public interests can form part of a broad-based development focus on small-scale and low-input production [3, 18]. Specifically, they should be relevant to health needs, scientifically valid, ethical, economically viable, culturally appropriate, and based on sustainable use of resources.

### **Nutrition and health**

Optimal diets must respond both to undernutrition and to overconsumption of energy [83, 88]. Nutrition policy must continue to prioritize food security, particularly for the poor in Sub-Saharan Africa and South Asia. But emphasis is best placed on nutritional balance as well as functional diversity. Quality and quantity of food need not be mutually exclusive. Functions that address the health outcomes of the nutritional transition, particularly through attention to energy density, glycemic control, and oxidative stress, define obvious priorities. Immunomodulating and related activities offer a response to conventional infectious diseases and HIV/AIDS. Stress suffered by urban populations, particularly the poor, from pollution of air, water, and food may be mitigated in part through diet [89].

Diversification of diet with indigenous fruits, vegetables, and whole grains and by moderate use of animal-source foods in both intact and processed forms is a first priority for policy and funding. Second, exotic nonstaples for which nutrient-specific (e.g., calcium in dairy products) and recognized health benefits exist can make important contributions to diet quality. Novel foods enhanced through processing or biotechnology with nutrient or functional components may be considered on a case basis relative to the well-defined needs of the target population.

Biofortification of cereal staples, while a potentially powerful tool to address specific micronutrient deficiencies, would further simplify food systems, decrease dietary diversity, and add to the economic advantage of large-scale producers [36]. Dietary diversification and attention to function in food processing, fortification, and FBDGs can complement narrowly targeted strategies and offset their potential adverse ecological, sociocultural, and biological consequences for human and ecosystem health.

Prior to intervention in any location, however,

it is essential to understand the existing nutrition-related strengths and weaknesses of the community's food system.

### Research and scientific priorities

Research defined by an implicit hypothesis of this review, that dietary diversity contributes to health and that biodiversity equates with dietary diversity, can catalyze the integration of these converging perspectives. Specific tests of the hypothesis might combine quantitative indicators of dietary and biological diversity with nutrition and health outcomes [36]. Program research relevant to the nutrition transition also requires establishing the validity of novel outcome measures. In addition to nutritional indicators such as child development, anemia, infection, and obesity, this undertaking might also draw on the disease-risk-reduction activities presented above within the framework of Dietary Quality Indices [88], or as represented by appropriate biomarkers [90]. Intake assessments could consider a measure of traditional foods in sustainability of the diet.

Analysis of food function, composition, digestibility, and safety takes high priority in its own right, as do biodiversity conservation and sociocultural and agronomic aspects of small-scale agriculture. Food processing can be simultaneously attentive to traditional food culture and to modern, more globalized, tastes. Evaluation of the impact of biotechnology on biodiversity and the well-being of vulnerable populations is also essential. Biotechnology as part of a balanced approach to development and improved food security can contribute to improvement of local crops that benefit and enhance local self-sufficiency [48].

Policy-oriented research can define and direct the manner in which socioeconomic, technological, and political factors affect human and ecosystem health. Research at the local, national, and international levels might explore farmer transaction costs and the pricing, institutional, technological, informational, sociocultural, and organizational factors that affect homestead production of nonstaple crops. Successful interventions are likely to be multisectoral, multidisciplinary, and problem-focused.

Wild foods, which are typically understudied, deserve particular attention both for basic characterization [46, 50–52] and for ecological, agronomic, and marketing research [91]. Developing-country scientists with knowledge of local resources, customs, and cultural values will play a fundamental role in identifying sustainable approaches to diet; external interventions must respect local qualification, insight, and commitment. A growing body of peer-reviewed data generated in developing countries addresses the health properties of indigenous foods. However, although large nations such as India, China, or Brazil can support extensive

research and development programs, in general progress depends on improvements in the scientific resources, opportunities, and infrastructure needed for adapting to, as the WSSD promotes for Africa, “world-class technologies” [3]. Full access to information technology is essential.

### Economic viability

Food-based approaches to health in developing countries must provide bona fide health benefits and value to consumers. Nonetheless, recognition of foods on the basis of enhanced quality presumably equates with economic value. In this context, function provides valid income-generating opportunities for producers, processors, and marketers, which in turn improves market stability. Appropriate products may be simply intact foods with recognized quality, in some cases identified varieties or genotypes, including potentially those enhanced through genetic modification. Processed cereal and legume-based complimentary food mixes provide models of nutritionally rational products [92].

Although investment in small-scale and sustainable agriculture offers the largest potential gains to productivity [18], governments continue to ignore this sector. Investments in rural infrastructure and small enterprises should accompany improved extension to small farmers in relation to sustainable practices, biodiversity conservation, and crop selection [3, 18]. Furthermore, credit access, organizational supports, and policies that reduce input costs and improve returns to farmers, as well as support development of marketing and processing sectors for traditional crops, are needed.

Agricultural subsidies and tariffs in developed countries constrain poverty reduction and agricultural development in developing countries [18], although the beneficiaries and benefits of economic globalization remain uncertain [11, 19, 93, 94]. With or without this “leveling of the playing field,” small-scale producers, when provided with appropriate supports, have comparative advantage in producing or wild-harvesting semiperishable and locally demanded crops, principally fruits, vegetables, traditional cereals, and animal-source foods, for urban and rural markets [18]. In South Asia, the fact that demand for such high-value commodities is rising three times faster than demand for staples underlines their key role in changing economies [18]. Given that in many cases the majority of rural farmers are women, this focus has important potential for alleviating gender inequities.

### Culturally appropriate foods and food systems

The key public policy needed to elevate food culture as a vehicle for ensuring that healthful foods form part of a socially, ecologically, and economically sustainable



system is simply to acknowledge, respect, and promote the fact. Decision makers with personal links to their own traditions may look to international, donor, and scientific support for the license to express this in public policy. The fact that traditional systems, once lost, are hard to recreate underlines the imperative for timely documentation, compilation, and dissemination of eroding knowledge of biodiversity and its uses. Food culture is an underutilized vehicle for promoting positive behaviors that should be part of the process of education and awareness-raising. Supporting cultural traditions within extension and public health activities, including recipe books and cooking classes, represents a tangible step [95].

### Local biodiversity resources

Cultivated and wild biodiversity, where it is part of traditional agricultural and food systems, can be best conserved and enhanced through rational use. On-farm conservation of intraspecific diversity and neglected and underutilized species is a priority for increased agricultural investment in biodiversity management. Adding value to biodiversity by coupling it to the market and to health increases farmers' likelihood of conserving and enhancing diversity [18], although raising awareness of farmers and others is essential [83]. Home gardens and urban agriculture offer contexts where functional diversity can be usefully promoted. Broader promotion of the combined role of biodiversity in human and ecosystem health provides a philosophical platform for positive individual and community action.

### Ethical and safety issues

Benefits from the enhanced use of biodiversity must legitimately flow to the undernourished poor, while potential negative consequences must be minimized and mitigated. Indigenous and traditional knowledge must be protected through legal and other mechanisms where appropriate [3]. Compensation for knowledge and genetic resources [3], as well as fair return for products, is a right of indigenous and local communities.

The promotion of foods for health benefits, whether for public health or commercial purposes, constitutes a health claim, stated or not. Even normal dietary constituents have potential consequences for safety, nutritional status, and health when their consumption is increased [96]. Although traditional diets offer many benefits, they are not inherently safe or all positive. Safeguards against adverse biological and social risks of promoting the use of traditional resources must be based on conscientious analysis and procedures for implementation. Because local communities often lack the basic information and empowerment to make deci-

sions, efforts to promote novel foods and technologies are challenged to satisfy the essential principles of the right to informed choice and the right to democratic participation. Safety, environmental impact, perceived risks and benefits, transparency, accountability, and equity also must be addressed [97].

Novel food products, whether they have enhanced nutritional or functional properties, can be tested by using *in vitro*, animal, and human studies and potentially followed through postmarket surveillance. Although international standards of evidence and evaluation may not be affordable in developing countries, claims remain subject to scrutiny and regulation based on credible evidence. Many products may be approved generically in other jurisdictions. Thus, improved access to information by developing countries has a high priority.

The promotion of indigenous foods requires special consideration. As well as being little studied for safety, these foods vary in genetic and environmentally determined composition. As the basis for building culturally appropriate dietary behavior and sustainable livelihoods, and as foods of longstanding use, they can be considered safe when consumed as part of a total diet, but should be a priority for research.

Principles that would minimize inappropriate decisions include ensuring that traditional and novel foods have good nutritional value; that they are evaluated within the context of total nutritionally balanced diet and are appropriate for *ad libitum* consumption; that they are relevant to the target population and national health and nutrition policies; and that the level recommended in the diet to obtain benefit is achievable and sustainable by the target population [97].

### Awareness and promotion

Perhaps the most immediate priority involves simply increasing awareness of the issues and raising the level of education among health-care personnel, policy specialists, and decision makers along the objectives for development of the WHO Global Strategy on Diet, Physical Activity, and Health [6]. Nutritionists can ensure that insights emerging from scientific research are available and are applied to best serve populations in need. Policies can incorporate these data into public health recommendations.

Subsequent efforts at public health education are likely to be most fruitful when they are two-way. Social-marketing methodologies that build on existing food culture and positive beliefs, participatory action, and context-appropriate forms of communication and promotion offer useful guidance [95].

Food and diet are of fundamental personal interest to all humans and thus provide a highly visible vehicle with local and global impact for linking health and sustainability. Nutritionists can play an important leader-

ship role in linking dietary and biocultural diversity. Diversity enriches the quality of life in health, sensory, social, intellectual, and moral terms and increases options and resilience for building livelihoods in the short term and for the future.

## Conclusions

Biocultural diversity provides a positive vantage point on priorities put forward at the WSSD, particularly for sustainable development in Africa and impoverished countries in Asia [3], as well as on global changes in health [6]. Nutrition offers a practical integration of the WEHAB themes, as well as, when placed within a sociocultural context, a nexus for changes in individual behavior and motivation essential for the fundamental shifts in production and consumption patterns upon which sustainability ultimately rests. Mutual consideration of biocultural diversity and nutrition can instigate reflective development research and applied action. A desirable dietary culture links human and ecosystem health.

Optimization of diet includes both physiological factors, as it mediates the risk of disease, and cultural factors, as it embraces values and seeks to define health-positive forms of human behavior. Strategies for reduction of the risk of disease can draw on empirical evidence relating to the nutrient content and functional properties of foods as well as the benefits of dietary diversity. Empirical data on the effectiveness, economic viability, acceptability, and sustainability of programs, policies, technologies, and interventions can also rationally direct the best ways to use biodiversity to meet nutrition and health needs. Nonetheless, a policy consensus related to the environment

and human well-being involves choices that must be based on philosophical and ethical considerations and common human sociocultural values. Without deliberate and concerted action, neither biodiversity nor health objectives can be realized.

In our opinion, approaches to complex interconnected phenomena are typically desegregated and inadequate for solving environmental health problems. Conversely, rational efforts that draw collectively on dietary diversity and biodiversity, rather than being dismissed as romantic, should be recognized as immediately pragmatic and ultimately essential. Faced with the scope of global poverty, social and dietary change, and environmental distress, anything less is a policy of despair and inevitable failure.

Education of nutritional, health, and agricultural professionals themselves with a holistic and responsive message can take a higher priority. Current policies for dealing with both health and resource use in developing countries limit expectations equally for the deliverers and the recipients of dietary interventions. A fundamental and authentically optimistic outcome of an integration of social, economic, and environmental considerations with health can be that of receptivity to greater possibilities based on the strengths inherent in traditional biological, cultural, and dietary diversity, and in evidence-based science.

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# Community-based school feeding during Indonesia's economic crisis: Implementation, benefits, and sustainability

Lisa J. Studdert, Soekirman, Kathleen M. Rasmussen, and Jean-Pierre Habicht

## Abstract

*The Indonesian Government initiated a community-based national school-feeding program in 1996. Implementation was decentralized and involved multiple participants. In 1998 we evaluated the implementation of the program and the perceived benefits for community stakeholders using a survey of principals in 143 randomly selected schools and follow-up with in-depth interviews and observations in a subsample of 16 communities. The evaluation covered the period of the 1998 Asian economic crisis, affording the opportunity to assess its impact on the program. The program was implemented in all targeted schools, with excellent community participation. Feeding was sustained through the crisis, in spite of a dramatic escalation in food costs. The families of schoolchildren, farmers, and those who prepared food received economic benefits. The snacks replaced those sold at schools and were of better nutritional value. The children benefited because the snacks compensated for losses in the home diet resulting from the economic crisis. Characteristics of the program that may be important in explaining its success include the involvement of a range of community stakeholders, engagement with existing village administrative structures, scope for local community adaptation and innovation, and the use of local foods that dispersed benefits and ensured sustained implementation during the crisis.*

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**Key words:** Community-based, economic crisis, Indonesia, school feeding

## Introduction

In the 1990s, the Government of Indonesia introduced a national school-feeding program that was planned and funded entirely with government resources. The program was ambitious, with broad goals that targeted children, schools, parents, and the broader village community (table 1) [1]. The program was part of the national poverty alleviation strategy of the Sixth Five-Year Development Plan for Indonesia, using school feeding as a community-level entry point. The mechanisms for program delivery were innovative as compared with other Indonesian government programs and in the context of school-feeding programs internationally [2, 3].

Pilot program trials were conducted in six provinces in 1991–92 [4]. Following evaluation of these trials, national implementation started in 1996 for approximately 2.1 million primary schoolchildren in more than 16,000 schools in villages designated as poor according to the Inpres Desa Tertinggal (IDT) or “Presidential Instruction for Villages Left Behind” program criteria. These criteria identified villages with economic growth less than the regional average according to a list of 36 indicators of village infrastructure and household socioeconomic factors [5, 6]. By 1998, the

TABLE 1. Goals of Indonesia's school-feeding program

- » To improve the health and nutritional status of primary schoolchildren
- » To improve the learning motivation and capacity of schoolchildren
- » To empower parents and community to be more concerned about their children's schooling, health, and nutrition
- » To improve the village economy with market opportunities for home or school-produced food products

schools in all IDT villages were mandated to implement the school-feeding program.

Implementation of the school-feeding program involved the provision of a mid-morning snack three days a week through the school year, for a total of 108 snacks a year. Program guidelines stipulated that the snack must not include the local staple food in order to avoid the impression that the food was a main meal that replaced a meal children would otherwise receive at home. Despite protests from industry groups at the time of the program's inception, the program guidelines also stipulated that industrially produced foods such as milk powder and noodles not be used [Soekirman, Personal communication, Jakarta, Indonesia, 1996]. To ensure that funding was directed into the local economy, only locally grown commodities could be used. The program also stipulated that children should receive deworming medicine twice a year [7].

Program funds, based on a per-snack, per-child, per-day amount, went directly from the national level to a local bank, bypassing the provincial and district levels of government. This was a new approach to delivery of program funds in Indonesia that was designed to minimize the attrition of funds that occurs as each level of government administers funds, and thus to ensure that more of the allocated funds reached the targeted program beneficiaries. From 1996 to late 1998, the allocated amount was 250 rupiah per snack in Java, Sumatra, and Bali, and 350 rupiah per snack in the rest of Indonesia (equivalent in 1996 to approximately US\$0.10 and 0.15, respectively). Only the school principal could withdraw funds from the local bank and to do this was required to present a menu plan signed by the village leader, the village midwife, and the heads of the local women's and school parents' associations. This process was designed to ensure that multiple local parties verified student numbers and were aware of the funds being provided for the program. The menu plan was prepared at the village or subdistrict level with technical advice from Ministry of Health staff.

The snacks were to have a minimum of 300 kcal and 5 g of protein. The type of snack served varied seasonally and regionally. Examples included *Getuk Ubi* (sweet potato with red palm sugar and coconut, from West Kalimantan) and *Bubur nasi sup* (a rice soup with meat, onion, and coconut, from West Nusa Tenggara). The program guidelines left scope for specific implementation plans to be designed according to village circumstances. The guidelines suggested that the village women's association be responsible for food preparation and that the village leader, parents, or midwife monitor the program [7].

The guidelines stated that when the snack was delivered to the school, the teachers should organize the children to wash their hands and give them a brief lesson on some aspect of health and nutrition, and that the children should pray according to their religion.

Figure 1 depicts school-feeding program inputs and stakeholder groups at the village level.

From 1996 the school-feeding program rapidly expanded. In the 1998–99 school year, all provinces were included, and the program served 8.1 million children in 53,000 schools, with a budget of 550 billion rupiah (equivalent to US\$50.5 million at the April 1999 exchange rates).

In 1997–98 Indonesia was severely struck by the Asian economic crisis. There were dramatic cuts in government programs, while donor funds were redirected to social safety net programs that targeted those worst affected. The school-feeding program was identified as integral to these efforts and was preserved within the International Monetary Fund loan agreement of July 1998 that required large cuts in government expenditures [8].

This paper presents the results of a study of the school-feeding program, its implementation, and its perceived benefits to stakeholders before and during the 1998 economic crisis. Although one of the program's stated goals was to improve children's health and nutritional status, the study did not aim to directly assess program impact in this area. The specific objectives of this study were to investigate how the school-feeding program was implemented and how the economic crisis affected implementation; and what the benefits were to the stakeholders involved in implementation.

## Methods

The study was based on a staged process that combined data-collection methods to form an emergent and adaptive evaluation strategy [9, 10]. Preliminary interviews and observations (stage 1) informed the design of a quantitative survey (stage 2). Data from stage 2 were used to select villages for intensive interviews and observations (stage 3). Insights from the results of stages 1 and 2 informed the design and approaches taken in the interviews of stage 3. Stage 3 was an adequacy study [11] that compared the findings with what was expected, rather than an impact study that compared intervention and control groups. All interviews were conducted with an interpreter who had English, Indonesian, and local language skills.

### Stage 1: Preliminary interviews and observations

Exploratory observations and interviews were carried out with key informants and program participants in 1996 and 1997, prior to the onset of the economic crisis. Key informants included government officials and program planners at the national, provincial, and district levels. Visits were made to schools in West Nusa Tenggara, Lampung, and West Java, where the early stages of program implementation were observed

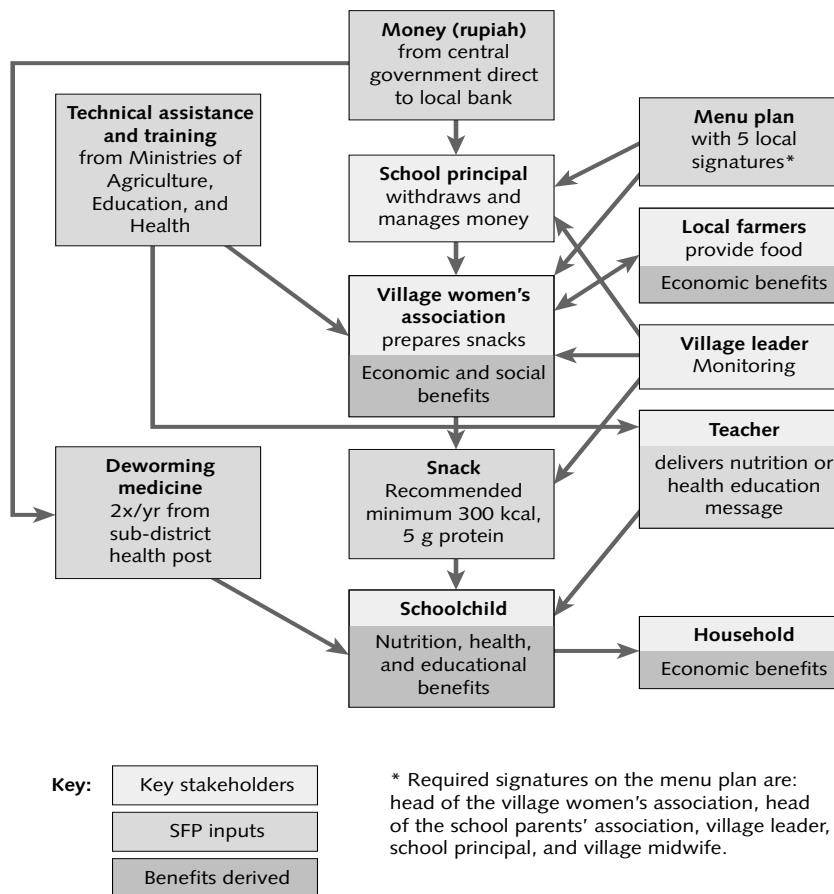


FIG. 1. Implementation flowchart for the Indonesia school-feeding program

and interviews were conducted with members of the village women's association, parents' association, school principals, village leaders, and the village midwife.

## Stage 2: School survey

In August 1998, the Ministry of Education and Culture planned a study to assess the impact of the ongoing economic crisis on primary education in five provinces: West Java, South Kalimantan, South Sulawesi, East Nusa Tenggara, and West Nusa Tenggara [12]. In each province, two districts were selected, from which two subdistricts were selected. These selections were made purposefully to form a sample of contrasting rural and urban areas. Fourteen schools were randomly selected from each subdistrict to make a total selected sample of 280 primary schools.

The Ministry of Education and Culture survey was designed to collect data on student enrollments, absenteeism, dropouts, and a number of school quality variables (e.g., budget, facilities, and teachers) in the three school years preceding the onset of the economic crisis and for the current school year, in which the crisis was ongoing, in order to assess changes over this period.

Of the 280 primary schools selected for the Ministry of Education and Culture survey, 143 were identified as being in IDT villages, where it was expected the school-feeding program was being implemented. An additional survey component was administered in the schools of these IDT villages. This component asked specifically about issues related to implementation of the program. The school principals were asked to complete all sections of the survey forms, and trained fieldworkers managed the survey forms.

## Stage 3: Interviews and observations

Sixteen school-feeding program schools were selected from the 143 schools in the Ministry of Education and Culture survey, where it was expected that the program was being implemented (stage 2), for an in-depth study of program implementation processes and benefits on the basis of changes in student absenteeism at the school since the start of the program. The eight schools that had shown the greatest increase in student absenteeism and the eight that had shown the greatest decline were selected. Absenteeism has previously been shown to respond to the introduction of a school-feed-



ing program [13–15]. Although no literature that we are aware of has related changes in absenteeism to differences in the quality of program implementation, we thought that the change in absenteeism might reflect the quality of implementation of the school-feeding program, and that choosing from the extremes of the changes would reveal maximum variability in implementation factors. The principal author was blinded to a school's record of absenteeism during data collection and analyses. The results from the absenteeism analysis have been reported elsewhere.\*

Interviews and observations were conducted between September and December 1998, during the economic crisis. The visits to schools were mostly unannounced, based on our experience in the preliminary fieldwork that showed this prevented over-preparation for the visit, particularly with school-feeding program activities.

At each school, data collection consisted of a series of open-ended interviews with five stakeholder groups: the school principal, the teachers, the parents, the women's association members involved in cooking, and the village leader. A core group of questions on program implementation was common to all interviews, combined with stakeholder-specific questions related to their role in the program. Women's association members were asked how they organized the preparation of the program snacks. The women were also asked what ingredients had been used for the snack served that day, what price they paid, and how much that commodity had cost a year ago. Past and present prices were always readily recalled. At selected sites, the prices given were validated at the local market.

Each interview took about one hour, and a set of interviews and observations at a school took one day to complete. Seventy-eight interviews were conducted with 172 informants, and observation of snack distribution was possible at 10 of the 16 selected schools.

### Data quality control and handling

Patton [16] describes four kinds of triangulation (methods, sources, analyst, and theory/perspective), of which we used two, methods and sources. The use of survey, key informant, and interview/observation data enabled triangulation of methods, and within the interview phase, the use of a core group of questions across stakeholder groups enabled triangulation of sources. Within an interview, multiple member checks (the reiteration of questions or responses) were used. Following administration of the survey, exit interviews were conducted with 13 school principals in two provinces to ascertain their understanding of the school-

feeding program component of the survey.

Peer debriefing and discussion of emergent findings was done with key informants in each province and with key ongoing interlocutors in Jakarta at the Indonesian National Planning Agency (BAPPENAS), UNICEF, and the Ministry of Education and Culture.

Survey data about program implementation from stage 2 were entered into the Statistical Package for the Social Sciences program [17] and analyzed for basic frequencies, with comparisons between the two groups of 8 schools selected for stage 3 and between these two groups of schools and all of the other 127 schools. Pearson chi-square tests were used to compare the findings from survey data with comparable interview and observation findings. A difference was considered significant when the *p* value was less than .05. In this study, a finding of no difference between groups is generally more important. We inferred that there was no important difference between groups when the magnitude of the observed difference was small and the pattern of differences was inconsistent.

All interviews were transcribed and analyzed for key emergent themes. Cases were contrasted across sites and across informant groups. Multiple passes were made through the interview and observation data to clarify and refine findings as they developed. The data were used to describe stakeholders' perceptions of the consequences of the school-feeding program and to examine the adequacy of program implementation in meeting the administrative protocols established for the program.

## Results

### Data validity and reliability and differences among schools

Comparison of the survey data on inputs and activities with interview and observation data on the same inputs and activities for each of the 16 selected schools revealed that six of the nine items were over-reported and three of the items were the same in the eight schools with decreased absenteeism. In the schools with increased absenteeism, seven of the nine items were over-reported, and two were the same. There were no major differences between the two groups of schools in the pattern of over-reporting. Table 2 shows that the magnitude of over-reporting was small, with a mean of 14% over-reporting in the survey responses relative to the more definitive interview and observation data for the same schools. None of the items was over-reported by more than 20%, except for the principal's self-report of training for the program, which was over-reported by about 25% in the survey.

Table 3 contrasts the survey data from the 16 selected schools with the other 127 schools surveyed. The com-

\* Studdert LJ. Indonesia's school feeding program: benefits in a time of crisis. Unpublished doctoral thesis, Cornell University, Ithaca, NY, USA, 2001.

pliance factors measured in the 16 selected schools were similar (less than 5% difference) to those in all the other 127 schools, with the exception of teachers receiving instruction manuals (greater among schools where interviews and observations did not take place,  $p < .05$ ) and students receiving deworming treatments (less among schools where interviews and observations did not take place, but not statistically significantly different because of variance between the two groups of eight schools). However, none of these differences point to any apparent systematic or otherwise significant differences that would affect our interpretation of the findings.

The data did not reveal any important differences between the two groups of eight schools for key program implementation inputs or activities; thus, the data did not support the hypothesis that the eight schools with improved attendance under the school-feeding program would show different implementation inputs than the eight schools where attendance declined.\*

#### Widespread implementation according to guidelines

All 143 schools in the stage 2 survey that were identified as being in villages where the school-feeding program should have been implemented (i.e., designated IDT villages) reported that they were actively implementing the program. Survey and interview/observation data showed program implementation to have been largely uniform and according to program guidelines for all key inputs and activities (tables 2 and 3), with the exception of provision of deworming medicine.

Interviews with key stakeholders in stage 3 revealed uniformity of implementation across the 16 sites. The awareness of program processes and adherence to these was marked, confirmed in observations, and indicated by the following descriptions:

[The process is] to wash hands, queue, and check the cleanliness of students, especially their hands and nails. Then we distribute the snack and tea and the child enters the class. We inform students about the nature of the snack and describe the materials and what nutrition the food has. We ask the cooks about what ingredients are in the snack. (teacher, Nusa Tenggara Barat)

Before the children eat the food, they have a prayer or a lesson about nutrition or health. Before the children are given the food, they wash their hands and pray. (teacher, South Sulawesi)

At the 16 sites where interviews were conducted, there was only one identified case of program funds

TABLE 2. Input and activity at schools selected for interview/observation ( $n = 16$ ): comparison of survey data from selected schools with interview/observation data from the same schools

Input and activity	Survey data (% of principals reporting)	Interview/observation data (% of sites selected)
Snack food to children 3×/wk <sup>a</sup>	100.0	93.8
Deworming medicine to children 2×/yr <sup>a</sup>	42.8	35.7
Instruction materials to school and women's association	93.8	100.0
Community meeting	100.0	93.8
Cooking equipment to women	100.0	81.3
Handwashing facilities at school	93.8	81.3
Health/nutrition lessons from teacher	100.0	81.3
Teacher has instruction manual	100.0	100.0
School principal has training	93.8	68.8

a. Prescribed amount according to government guidelines and budget provided.

TABLE 3. Comparison of survey data from the 16 schools<sup>a</sup> selected for stage 3 data collection with all other schools ( $n = 127$ )

Input and activity	16 selected schools (% of principals reporting)	All other schools (% of principals reporting)
Snack food to children 3×/wk <sup>b</sup>	100.0	100.0
Deworming medicine to children 2×/yr <sup>b</sup>	42.8	65.4
Instruction materials to school and women's association	93.8	98.4
Community meeting	100.0	98.4
Cooking equipment to women	100.0	96.9
Handwashing facilities at school	93.8	98.4
Health/nutrition lessons from teacher	100.0	97.6
Teacher has instruction manual	100.0	66.1
School principal has training	93.8	97.6

a. The statistical test compared the two groups of 8 schools with the other 127 schools (see description in text).

b. Prescribed amount according to government guidelines and budget provided.

\*Studdert LJ. Indonesia's school feeding program: benefits in a time of crisis. Unpublished doctoral thesis, Cornell University, Ithaca, NY, USA, 2001.

being used inappropriately. At this school, it was found that the principal was implementing the program independently, without community involvement, and there were suggestions from other informants of mismanagement of program funds. Nevertheless, a snack distribution was observed at the school, although the ongoing frequency could not be determined.

One procedural complaint that was occasionally heard in interviews concerned delays in the disbursement of funds from the government to the local bank. However, there was no evidence that this disrupted implementation. Indeed, it is notable that those responsible ensured that implementation proceeded, as evidenced by this particular comment:

The distribution of money is sometimes late, but to overcome this I borrow money from school cash. (women's association member, Nusa Tenggara Barat)

### High degree of community participation in program implementation

At 15 of the 16 interview and observation sites, it was determined that members of the village women's association prepared the school snack. At 10 sites multiple teams with two or more members had some form of rotating schedule, and at the other sites there was a single team of three to five women. The specifics of these preparation arrangements were unique to each school.

The women were asked if the work was a burden to them, and they invariably insisted that it was not. Moreover, the women talked about their motivation to perform the work, including social interaction with other women while cooking, and said that they were happy to do the work for the benefit of the children:

[The school-feeding program is good because] students get healthy and I get activity. Sometimes I only cook at home, but with this I get activity away from home. (women's association member, South Sulawesi)

I learn to make better food and I learn by example how to cook hygienically. (women's association member, Nusa Tenggara Barat)

Throughout the survey, 75% of principals reported that commodities for the snacks came from local markets, 56% from local farmers, and 49% from local gardens (the total exceeds 100% because food was purchased from multiple sources). Markets in neighboring villages were the other main source (43%). Seventy-two percent of those surveyed said the school-feeding program had benefited farmers by giving them opportunities to sell produce.

In addition to the role of the women's association members and local farmers, the interviews revealed that

there were multiple ways in which other community members participated:

I give advice to the groups: they must cook food the children like. If the children don't like the food, they must change. Sometimes I look at food and the children don't finish eating the snack; therefore, they must not like it, and after that I give advice to change the menu. (village leader, South Kalimantan)

Sometimes I come to school to try the food, when I have the opportunity. Last year I came about six times. Sometimes I get food from the children. I come to test the food. (head of parents' association, South Sulawesi)

The midwife gives advice about the menu, such as how many calories. She tells us we should wear a mask and gloves when cooking and be clean. She tells us not to touch already cooked food. (women's association member, West Timor)

### Food costs increased but feeding continued

Dramatic increases in food commodity prices were reported at all interview and observation sites, reflecting the effects of the ongoing economic crisis. The women reported that the price of items used in the snack they prepared the day of our visit had increased by an average of 160% in the previous 12 months (this figure is a simple mean of the increase in prices of all food items and gives no weighting to the relative proportions of the different commodities used in a particular snack). This figure is broadly consistent with official national data for this period that found the average increase in food prices to be 135% [18]. The range of increases reported across the 16 interview and observation sites was 73% to 250%.

At least one stakeholder at each site spoke about the impact of the increased prices on snack size and/or quality, but there were no reports that snacks were being served less than the prescribed three times per week:

The crisis does have an impact, because the price of the materials for school feeding should be adjusted to the real price of the day. The size of the snack is smaller. (teacher, Nusa Tenggara Barat)

In 1997 the children got two cakes and one glass of tea. Now they get only one cake. (school principal, South Kalimantan)

Before the crisis the kind of food for children was varied—eggs, vegetables, and sometimes meat—but now this is not possible. (school principal, South Kalimantan)

At 14 of the 16 interview sites, it was reported that children were receiving less food at home since the crisis:

The [children] now have a big meal only at lunch. Here the rice is 4,000 rupiah per kilogram, and not less than 3,000 rupiah per kilogram, so of course many families can't support having rice three times per day. Now they don't have breakfast or eat only cassava. (teacher, South Kalimantan)

Before, the children drank milk every day, but now they only drink it sometimes. And now we eat meat only infrequently. If there is a wedding party, we eat meat. (women's association member, South Sulawesi)

### **An income transfer benefit for community participants**

There was initially some difficulty in identifying whether there was some incentive for women who worked to prepare snacks. In the survey, less than 12% of school principals responded affirmatively to the question about incentives. With careful questioning, the women at 15 of the 16 interview sites reported that they did receive some compensation for their work. However, they reported that the value of that compensation had diminished with the crisis. The site that did not report such benefits was that where the women's association was not involved.

At 11 sites women reported that they received a monetary payment; at 10 sites they reported that they received "leftover food":

There is explicitly no profit. But we get a lot of food left over, e.g., rice, banana, and cooking oil. So there is no incentive in the form of money. If any food is left, we distribute it among those who work. (women's association member, Nusa Tenggara Barat)

Before the crisis we got 12,000 to 20,000 rupiah each time we cooked. Now there is no profit. We try to reduce the size of the food and make it smaller. Sometimes we can take food home. The rest of the ingredients, e.g., leftover sweet potato skins, we can feed to the cows. (women's association member, West Timor)

There was widespread acknowledgment that farmers were receiving benefits from the program. At all interview and observation sites, it was reported that farmers received benefits from selling produce for snack preparation:

The farmers sell banana leaf and sell cassava and banana and rice. The farmers are happy because they can sell these products and their children get the food. (village leader/farmer, South Kalimantan)

Because most of the materials for snacks are from the community, the economy can increase and

grow. We get good prices from the women's association members. (parent/farmer, South Sulawesi)

At 15 of the 16 interview and observation sites, it was reported that an important benefit of the school-feeding program was the money parents saved on feeding days. This benefit had not been identified in earlier stages of data collection (precrisis), and thus was not asked about in the survey. The saving appeared to come about in two ways: by enabling parents not to give children money to buy snacks from local vendors (an important feature of the schoolyard and day), and by saving money that would be spent on food given to the children at home (breakfast and/or lunch). Although it was not possible to determine the size of these savings, a range of comments made this a clear message:

The school feeding helps with the effects of the crisis because the parents can reduce the money they give to the students. The students cancel lunch because they get food from school. It is better, because they can eat the food from lunch for dinner. (parent, South Kalimantan)

School feeding is helpful for the crisis because it gives food to the children. With the crisis, the food for children at home is not the same as before. The material for food is very expensive. (village leader, South Sulawesi)

### **School-feeding snacks of better nutritional value than food from vendors**

As reported above in the description of the program's implementation, the school-feeding program snacks generally included a diverse range of commodities and were of sound nutritional value. Although the nutritional quality declined with the crisis, the snacks were still of superior quality to those otherwise bought from the vendors who operated informally at schools. Their snacks included flavored ice, sugared coconut or "fairy floss" treats, and commercially produced fried cassava or potato chip packets. The finding that parents saved money on days of school feeding because they did not give their children money to buy food from vendors supports the proposition that nutritional school-feeding program snacks replaced these vendor snacks. It was not possible to quantify these observations in the study conducted.

## **Discussion**

The evaluation for adequacy [11] of the Indonesian school-feeding program showed it to be well established and implemented across a number of provinces and contrasting rural-urban, social, and environmental settings, even during a period of adverse circumstances.

This conclusion is based on survey data on implementation collected from 143 principals of schools representative of all the schools in which the program should have been implemented in the five provinces. Probing interviews and observations among the program stakeholders in 16 of these schools validated the principals' reports, in spite of a tendency to over-report specific implementation factors in survey responses. The program was implemented to a major and adequate extent in all schools, including one school that was not following the financial management procedures correctly. The 16 schools had originally been chosen on the basis that they represented extremes on the dimension of changes in school attendance. It turned out that all schools (the 16 and the remaining 127) were similar in their reports of implementation. Therefore, we conclude that our findings in the 16 schools were similar to what we would have found in the full sample of schools, even though the 16 were not a random sample of the total. Because the 143 schools were identified through a combination of purposeful and random selection, we infer that our findings of widespread, adequate implementation in these schools can be extended to all schools in IDT villages in these five provinces.

In this adequacy evaluation, we compared the findings with the official criteria of performance for the school-feeding program and with stakeholders' perceptions about the program. Control groups without the program, which are necessary for a conventional impact evaluation [11], would have been superfluous in this study, because without school-feeding program activities there could be no program-related findings. The differences between program and nonprogram schools would obviously have been important, but much less relevant to the questions of program management and policy makers that we set out to answer: whether the program was implemented as expected and what benefits were perceived by stakeholders.

Apart from the appropriateness of the design, the quality of the observational and interview data must be adequate to infer that the principals' survey reports were correct. The "truths" reported by the survey and interview respondents were those perceived by the respondents and were further interpreted by the interviewer. They are thus subjective. However, we believe that the several methods of data-checking that were used across the stages of data collection (e.g., key informant interviews) and within stages (e.g., data checks across stakeholders and within interviews, and verification through observations) ensure the validity of the data and their interpretation. Where there were discrepancies between the reports of informants, they reflect the specific knowledge of the informant and not deliberate biases. The only exception was the over-reporting by school principals of their own training for the program. This exaggeration, however, had no effect on the actual implementation of the program.

### **Strengths of program design and implementation**

Several features of the program's design were both innovative in the context of program implementation in Indonesia and, we believe, critical to the fact that implementation was maintained through the crisis. These are summarized in table 4.

In relation to financial benefits to the women who cooked, it should be noted that the basis for selection of the women appeared to vary between villages. Selection was described, variably, as being based on those "who lived closest," "who volunteered," and "who are poor." Similar reasons were given for selecting those farmers from whom to purchase food commodities.

The fact that school-feeding program snacks were highly valued by households with children at school is attributed to several factors: families saved money because they did not have to give money to the children to buy snacks from vendors; in some cases, the school snacks replaced food normally provided at home (breakfast and/or lunch); and the superior nutritional quality of program snacks compared with vendor-purchased snacks was recognized. Although it would seem there might have been a negative impact on the school-based vendors, this was not identified in the data.

### **Weaknesses in program implementation**

The strengths of the program's design and implementation lay in the village-based management structures and implementation mechanisms (table 4). The program weaknesses lay in a lack of external technical inputs and expertise to complement this decentralization. In particular, the widespread failure to provide deworming medicine twice yearly was attributed to the failure of health authorities at the subdistrict and district level to provide the medicine. We suggest that without the flow of program monies through these levels of government, there were no triggers or incentives for these authorities to fulfill this role.

A challenge for the future implementation of the program was to improve the nutritional quality of the snacks in the postcrisis setting. A range of program stakeholders readily acknowledged that since the crisis the snacks were now "half" of their precrisis size and contained less of the "expensive ingredients," such as meat, eggs, and some vegetables. Independent of the monetary constraints, there was a suggested role for health authorities in training women on the size of the snacks and their nutritional value, and this was not being fulfilled either before or during the crisis. The reasons for this are probably similar to those that underlay the weaknesses in the distribution of deworming medicine.

TABLE 4. Summary of factors identified as critical to the successful and sustained implementation of Indonesia's school-feeding program during the 1997–98 economic crisis

Factor	Explanatory notes
Implementation engaged established groups and structures in the village setting	The school principal, teachers, women's association, village leader, and midwife were all identified individuals or groups within the local political/administrative structures
Multiple local parties signed to school snack menu plan before funds could be received	The mechanism of requiring five local signatories aimed to develop shared knowledge of, and responsibility for, the program's implementation
There was a requirement to use local foods, not industrially produced food products	Enabled some purchasing power to be maintained during the period of rapid inflation in food prices, particularly for industrially produced commodities compared with locally grown foods <sup>a</sup>
The process of preparing menu plans and snacks was not specified and was left to the individual village and/or school communities to design	The selection of seasonal foods and the organizing for cooking was left to local groups to plan according to local needs and capacity
Women who cooked were motivated by social interaction, learning new cooking methods and recipes, and satisfaction in preparing food for children at school	All cited as reasons women were motivated to spend the time to cook school-feeding program snacks, in addition to the financial benefits identified

a. The average increase in the price of the "basketful" of commodities for all villages and schools was 160%, as compared with a 225% increase over the same period in the price of noodles, the commodity that industry leaders had suggested the program use at its inception [19].

## Conclusions

The Indonesian school-feeding program is an important example of how a community-based school-feeding program can be designed and implemented to involve, and provide benefits to, a range of community stakeholders, including schoolchildren. The benefits to program stakeholders included income benefits to the families of the schoolchildren, the farmers from whom the food was purchased, and the women who prepared the food. We also conclude that the program contributed to better nutrition of the schoolchildren, because the program snacks were of better nutritional quality than the vendors' snacks they replaced, and because the program provided food during a period of economic stress for households. Moreover, we identified widespread community acknowledgment of the linkages between children's education and nutrition and the role of the school-feeding program in this, particularly during the crisis. Further educational benefits, in particular to school attendance, are presented elsewhere.\*

The documented successes, in particular the sustained implementation, are all the more remarkable given the significant change and turmoil Indonesia experienced in 1997–98. Given the program's success, despite such conditions, we believe the innovative features of the program might be further tested in the implementation of community-based programs.

\*Studdert LJ. Indonesia's school feeding program: benefits in a time of crisis. Unpublished doctoral thesis, Cornell University, Ithaca, NY, USA, 2001.

For school-feeding programs, they form the basis of valuable lessons on the potential for such programs to benefit a wide range of community stakeholders, as well as the children to whom they are targeted.

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The findings, interpretations, and conclusions

expressed in this paper are entirely those of the authors and do not necessarily represent the views of the institutions they work for.

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# Weight of foods and number of portions consumed are not proxies for expressing nutrient intakes in field studies

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## Abstract

*In order to determine whether simplified indicators for usual consumption of selected food groups, specifically those derived from either the percentage of the number of daily portions, the percentage of total daily weight consumed, or both, could serve as proxies for the conventional expression of daily energy intake, these indicators were computed and compared from food-frequency data in a data set. Food consumption was reported in frequency categories and portion sizes per month, per week, or per day, and the cumulative sum was divided by 365 to provide a daily average. The survey was done in the township of Santa Cruz and three hamlets of a rural county seat in Guatemala. Data from food-frequency questionnaires from 269 individuals (55 men and 214 women aged 16 to 86 years) were analyzed. For foods of plant origin, the percentage of total energy, percentage of total food weight, and percentage of total number of portions consumed showed low correlations ( $r < .45$ ). When subdivided into specific foods and food groups (fruits and vegetables, red meat, etc.), marked differences were revealed across sites and among different indicators of consumption. Despite the simplicity of calculation, neither the percentage of weight of food in a group nor the percentage of portions consumed could serve reliably as proxies for their contributions to the percentage of total energy in this rural population in Guatemala.*

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**Key words:** dietary intake, dietary energy, food frequency questionnaires, nutritional surveys, Guatemala

## Introduction

Dietary assessment methods have acquired increasing interest in recent years [1–5]. Some new methods have been developed and validated in the industrialized world, and researchers in the developing countries have adapted versions of these same instruments [6–9]. When food-frequency questionnaires are used to assess dietary intake, they are easily modified to suit specific research needs. These modifications, however, can make difficult the use of computer software packages originally designed for input and analysis of data derived from unmodified questionnaires.

The greater the extent to which data reduction and interpretation of an instrument are simplified, the closer is the information to the individual of interest and the more empowered is the practitioner—or even the patient—in terms of the management of his or her own health. A simple count of food or beverage items and servings is mathematically straightforward; it can be managed by all individuals with a secondary-school education. Applying the weight factor of a serving portion corresponding to common household measures (cup, spoon, etc.) to these foods increases the complexity of the mathematics but still allows for the use of a hand calculator.

With these considerations in mind, we explored the ability to create valid proxies for the contribution of total energy of food, based on the weight of food or the number of portions, from a food-frequency questionnaire for the assessment of concordance with the recommendations of the World Cancer Research Fund (WCRF)/American Institute for Cancer Research Guidelines for the prevention of global cancer [10]. We used archival data generated with a food-frequency questionnaire modified from the original instrument of Willett [11] in the Nurses Health Study.



## Methods

### Population

The data were collected in the Republic of Guatemala in a region of the eastern highlands, Santa Rosa Province. This is a rural and agricultural setting in which coffee cultivation and subsistence farming are the primary pursuits for the largely ladino (Spanish-speaking individuals of mixed Spanish-Mayan descent) peasantry who inhabit towns, townships, hamlets, and homesteads along the mountainous ridge that runs toward the Caribbean coast. The climate is temperate year round; the dry season lasts for six months, and the other six have tropical monsoon rains. Illiteracy is widespread, especially among adult women. The subjects were invited to participate if they were between 16 and 86 years old; the rejection rate was less than 5%. However, since the interviews were conducted only on weekends, male subjects were rarely available, because they were working in the fields. The sample in this study represents a convenience sample of the population accessible in their homes or in the streets on the interview days. In 1994, a total of 271 individuals from the county seat of Santa Cruz Naranjo and its hamlets (El Naranjo, Potreríos, Don Gregorio, and Santa Cruz Naranjo), were interviewed. From these, we obtained 269 usable individual data forms, including 55 men and 214 women aged 16 to 86 years. This database has been used in earlier publications [9, 12].

### Questionnaire interview instruments

The original Willett [11] semiquantitative food-frequency questionnaire, which lists 61 foods, served as the template for the instruments used in the present study; it was developed in the Spanish language and in common local names for the foods of interest. A research activity in Santa Rosa Province, analogous to the Costa Rican study of Campos et al. [6] and involving the same analytical laboratories and collaborators in Boston, had been planned. For use in Santa Rosa, preliminary interviews with key informants were held to obtain 24-hour recalls of foods and beverages consumed. Questions about consumption of seasonally available foods were asked in the county seat and its peripheral hamlets. Approximately 45 individuals were interviewed once to determine which foods to incorporate into the food-frequency form. Two focus groups were used to determine which items on the Willett questionnaire were not or were never consumed by the study population. If a food (e.g., milk, white bread, or coffee) was already listed in the basic instrument, its code number was conserved. Substitutions were made of code numbers for items in the Willett questionnaire that were not part of the diet of the study population. Guatemalan staples such as maize tortillas and tamales

occupied vacated code numbers in the list. When the adaptation was completed, the food-frequency questionnaire for the Santa Rosa population had a final roster of 88 food and beverage listings for interviews. For purposes of analysis, however, certain items, such as different preparations of beans (*Phaseolus vulgaris*), were aggregated into a single food category. In order to assess food quantities, the portions from all questionnaires were standardized to cups (240 ml), spoons (15 g), teaspoons (5 g), or 100-g portions (and their fractions), according to the information registered in the questionnaire forms.

The Willett food-frequency questionnaire was designed and developed for self-administration [13]. However, because of the high rate of illiteracy among the study subjects and doubts about their ability to understand concepts such as current and historical frequency of consumption, we used a team of six trained students from the nutrition program at the national university to administer the questionnaire in Santa Rosa.

### Data and statistical analysis

The instrument recorded the frequency of each food consumed per month, week, or day; after all portions and frequency categories had been registered in an Excel database, they were multiplied to obtain total portions per year and then divided by 365 to obtain the daily quantities. Energy values were calculated according to nutritional values from the Institute of Nutrition for Central America and Panama (INCAP) food-composition tables [14].

The mathematical conversions described above allowed us to determine the percentage of daily energy obtained from a given food item, as well as from the respective food groups. For each individual, the weight and number of portions consumed of each food and beverage, and of each food group, were calculated. The percentage of consumption from each food group (fruits and vegetables; red meat; starchy and protein-rich plant foods; fats and oils; and all foods of plant origin) [10] was calculated in terms of weight, portions, and energy. Bivariate linear regressions (Pearson correlations) between portions and energy, weight and energy, and weight and portions were performed for each food group. Two-way analysis of variance, with the value according to food group as the dependent variable, was carried out to establish differences between communities and indicators of consumption (i.e., percentage of weight, percentage of portions, and percentage of energy).

## Results

There were no differences according to gender or age

in the data. The overall distribution of food sources is not atypical or unexpected for a rural, agrarian population in the interior of Guatemala. About 78% of the total energy came from plant sources, and the remaining 22% from sources of animal protein or fat. Fifty-six percent of total energy came from starchy or protein-rich plant foods (cereals, legumes, and tubers), primarily maize (in the form of tortillas) and black beans, with some contribution from white bread, rice, and potatoes. Twenty-two percent was from fruits and vegetables. Consumption of ethanol, meat, separated fats, and milk and its products was low, whereas that of fruits and vegetables, legumes, and grains was adequate; only sugar was consumed in excess according to the WCRF recommendations [9].

Table 1 provides the mean ( $\pm$  SD) values of the percentages of the number of portions, weight, or dietary energy contributed by foods of plant origin, and foods from each of four index food groups (fruits and vegetables, red meat, starchy and protein-rich plant foods, and fats and oils) to the cumulative total for each of the respective units of expression. For the township population (Santa Cruz) and for each of the peripheral hamlets, the mean intake, as expressed by any of the three indicators, is consistent among sites across the row in foods of plant origin. Moreover, within columns, the roughly comparable overall percentage values are also similar. The same was true for the aggregation of "animal-origin" foods (data not shown).

Turning to specific food groups, however, we see

a different pattern. For fruits and vegetables and for starchy and protein-rich plant foods, the values across the row for any given unit of expression are still closely comparable; but for fruits and vegetables, the weight and portion percentages far exceed the contribution of energy, whereas the converse is true for starchy and proteinaceous vegetable items. With respect to red meat, there is roughly a threefold difference between the mean intakes for the population of the township and that of the poorest and most remote hamlet (Potreríos), regardless of which expression is used. Moreover, for comparison within columns, numerical discrepancy, as found for the previously mentioned food groups, is obvious for red meat as well (table 1).

For fats and oils (table 1), there is again a 2.5- to 3-fold difference between the mean intake in Potreríos, according to any of the indicators, and that in the site with the highest consumption, which in this case is the hamlet of El Naranjo. Each indicator produces a consistent intercommunity rank order for both red meat and fats and oils.

The Pearson correlation coefficient values and their squared ( $r^2$ ) expressions were computed for each of the three bivariate combinations of the indicators. The matrix of the  $r^2$  values is presented in table 2. We have arbitrarily designated an  $r^2$  value of 0.6 as "acceptable." The percentage contributions of grams of items consumed and serving portions of items consumed, on an individual basis, have low associations for all groupings, except for the combination of red meat items ( $r^2 = .67$ ).

TABLE 1. Percentages of number of portions, weight, and energy from different food groups (mean  $\pm$  SD)

Food group and indicator	Santa Cruz (n = 53)	El Naranjo (n = 96)	Don Gregorio (n = 65)	Potreríos (n = 55)	Total (n = 269)
Plant origin					
Portions	74.4 $\pm$ 9.0	72.3 $\pm$ 9.4	75.1 $\pm$ 8.8	78.1 $\pm$ 14.7	74.6 $\pm$ 10.7
Weight	78.7 $\pm$ 9.6	75.3 $\pm$ 13.2	75.6 $\pm$ 13.2	84.8 $\pm$ 11.4	78.0 $\pm$ 12.7
Energy	75.9 $\pm$ 13.4	75.4 $\pm$ 12.0	76.5 $\pm$ 10.6	85.1 $\pm$ 10.9	77.7 $\pm$ 12.3
Fruits and vegetables					
Portions	31.8 $\pm$ 8.9	29.0 $\pm$ 10.4	30.5 $\pm$ 10.0	37.8 $\pm$ 10.5	31.7 $\pm$ 10.5
Weight	54.4 $\pm$ 12.1	47.1 $\pm$ 15.0	50.0 $\pm$ 15.7	59.8 $\pm$ 12.5	51.8 $\pm$ 14.9
Energy	19.4 $\pm$ 13.7	19.4 $\pm$ 13.9	21.2 $\pm$ 13.3	33.1 $\pm$ 14.3	22.6 $\pm$ 14.8
Starchy and protein-rich plants					
Portions	42.5 $\pm$ 11.2	43.7 $\pm$ 10.3	43.6 $\pm$ 13.1	43.1 $\pm$ 9.1	43.3 $\pm$ 10.9
Weight	24.0 $\pm$ 10.8	28.8 $\pm$ 11.1	26.3 $\pm$ 12.7	25.8 $\pm$ 9.0	26.6 $\pm$ 11.2
Energy	56.5 $\pm$ 16.2	57.8 $\pm$ 13.6	55.3 $\pm$ 18.3	53.3 $\pm$ 14.1	56.0 $\pm$ 15.4
Red meat					
Portions	2.3 $\pm$ 1.6	2.5 $\pm$ 1.9	2.1 $\pm$ 1.6	0.8 $\pm$ 1.1	2.0 $\pm$ 1.7
Weight	0.7 $\pm$ 0.6	1.3 $\pm$ 1.2	1.2 $\pm$ 0.9	0.4 $\pm$ 1.0	1.0 $\pm$ 1.0
Energy	2.0 $\pm$ 1.6	3.1 $\pm$ 2.7	3.2 $\pm$ 2.4	1.0 $\pm$ 1.2	2.5 $\pm$ 2.4
Fats and oils					
Portions	3.1 $\pm$ 2.9	5.0 $\pm$ 6.7	3.7 $\pm$ 3.1	2.0 $\pm$ 2.3	3.7 $\pm$ 4.7
Weight	0.5 $\pm$ 0.5	1.0 $\pm$ 1.2	0.9 $\pm$ 0.8	0.3 $\pm$ 0.4	0.8 $\pm$ 0.9
Energy	3.3 $\pm$ 3.3	4.6 $\pm$ 5.1	4.4 $\pm$ 3.8	2.0 $\pm$ 2.5	3.8 $\pm$ 4.2

TABLE 2. Comparison of Pearson correlation coefficients ( $r^2$ ) for percentages of weight, energy, and number of portions from various food groups<sup>a</sup>

Food group	Weight vs portions	Weight vs energy	Portions vs energy
Plant origin	0.31	0.31	0.44
Fruits and vegetables	0.53	0.42	0.47
Starchy and protein-rich plants	0.41	0.47	0.44
Red meat	<b>0.67</b>	<b>0.81</b>	<b>0.66</b>
Fats and oils	0.25	<b>0.61</b>	0.37

a. Correlation coefficients above  $r^2 = .6$ , which are considered “acceptable” values, are shown in boldface.

Moreover, at the level of disaggregation of plant origin versus animal origin, the squared correlation coefficients for indicators for items of plant origin are between .31 and .44, no matter which two indicators of the three are compared in a bivariate fashion. Our main hypothesis, however, that the weight of food or the number of portion sizes serves as a proxy for their contribution to total energy, is not supported. The correlation data for this hypothesis present a disappointing array, as only three of the eight associations for food groups—two for red meat and one for fats and oils—surpassed an  $r^2$  value of .60. As exemplified in figures 1 and 2, for the food group of fruits and vegetables, the higher association ( $r^2 = 0.53$ ) for weight versus portion number fades to a modest value when energy versus weight ( $r^2 = .42$ ) or energy versus portion number ( $r^2 = .47$ ) becomes the associations of interest.

In table 1, which compares the contribution of fruits and vegetables according to the three indicators, we can appreciate some of the bases for the discrepancies. If

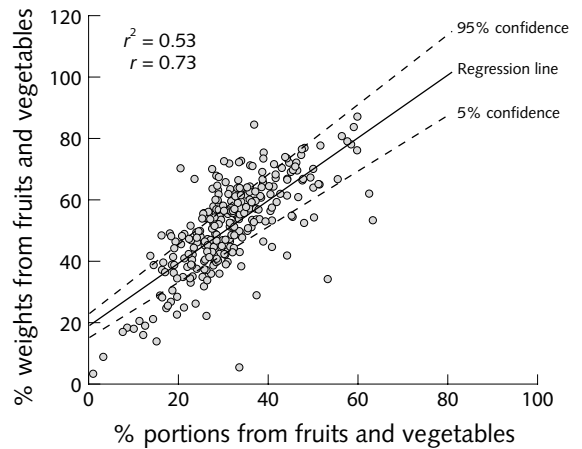


FIG. 1. Scattergram of the 269 simultaneous data points derived from the estimation of the individual’s portions of fruits and vegetables as a percentage of all daily portions (x-axis) and the same food group expressed as a percentage of the total daily weight of food (y-axis).

we isolate the Santa Cruz township and the Potreríos contribution by weight, this class of food items contributed 54% of the dietary weight in the former and 60% in the latter, a ratio of 9:10. Fruits and vegetables, however, contributed 19% of the total energy in the former community and 33% of the total energy in the hamlet, for a 2:3 ratio. The obvious conclusion is that a different selection of fruits and vegetables was to be found in the two sites within the county, and that more energy-dense fruits or vegetables make up the fare in Potreríos.

The analysis of variance showed separate, statistically significant ( $p < .001$ ) effects of community or type of indicator for plant origin, fruits and vegetables, red meats, and fats and oils; only type of indicator was

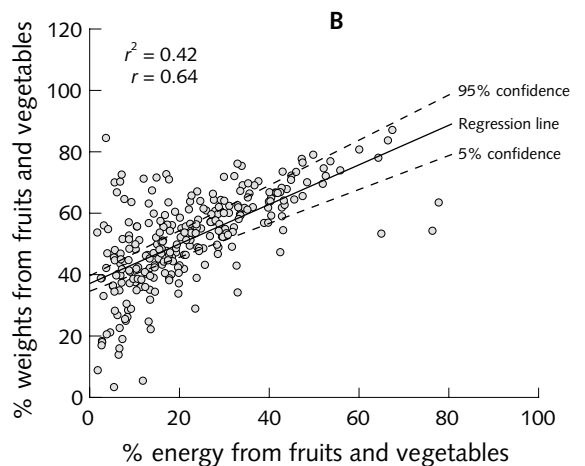
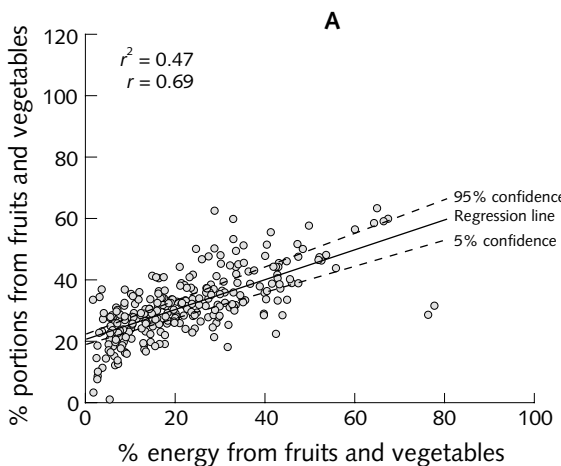


FIG. 2. A. Scattergram of the 269 simultaneous data points derived from the estimation of the individual’s intake of fruits and vegetables as the percentage of total daily energy intake (x-axis) and the same food group expressed as the percentage of all daily portions of food (y-axis). B. Scattergram arrayed for the correlation of the percentage of total daily energy (x-axis) versus the percentage of daily weight for the same food group.

significant for starch and protein-rich foods ( $p < .001$ ). The combined effect of community and type of indicator for calculation was statistically significant ( $p < .01$ ) only for the red meat group. These data indicate important differences between communities and type of indicator in practically all food groups.

## Discussion

An instrument devised in Boston, Massachusetts, USA, for use with 100,000 North American nurses [13, 15] was translated and adapted for use with the Spanish-speaking populations of Costa Rica, Mexico, and Spain itself [6, 7, 12, 16]. In Guatemala [9, 12], a similar modification was applied to a field survey. In the process of reducing and analyzing the data to create these publications, the inordinate dependence on sophisticated computer software and food-composition databases was recognized when it came to expressing values with reference to total energy. The raising of the questions of simplification of the management led to the present exercise.

Despite the fact that computer technology has become ever more available, accessible, and user-friendly, there are a number of reasons why reliance on other than nutrient-quantified data may be appropriate in clinical and public health settings. In some parts of the world and among some disadvantaged populations, even the cheapest computers are prohibitively expensive or impractical because of the absence of electricity; here, solar-battery hand calculators are the most reliable form of computation device. Moreover, in the clinical setting and for patient and public education, one may be able to empower both practitioners and clients by putting the deciphering and decoding of information into their own hands; an elementary scoring system reaches toward this ideal. This has been reflected in the development of various scoring indexes for dietary habits [17–19]. Moreover, the accuracy and representativeness of the quantitative values in food-composition tables may be called into question—or have gaps—with respect to nutrients of interest; hence, it becomes self-delusion to treat the numerical values, carried to several decimal places, as reliable.

All of the aforementioned considerations made

an inquiry into the feasibility of proxy indicators a worthwhile endeavor. With very limited success—and only at the level of the greatest aggregation—was either of the two proxy indicators (portion number or weight of consumption) a reasonable substitute for the comparable expression based on total energy in the denominator. It is perhaps not surprising that this is true, since the densities of the various nutrients and food constituents of interest have a wide spectrum, and whole foods of plant origin have an energy density quite distinct from foods of animal origin. It is not a matter of mixing apples and oranges, but rather of mixing apples and oranges with cheese and lard. These density gradients account for the impossibility of taking the shortcut approaches that would have made the calculations for individuals accessible by a simplified scheme on a hand calculator.

Clearly, if the primary epidemiological observations were generated in units of portion numbers or food weight, then predictive associations and goals and recommendations could be expressed in these same units. Currently, for reasons enumerated by Willett [11], nutrients of interest are expressed in relation to total dietary energy, and epidemiological association requires adjustment for dietary energy. However, in the original data sets of epidemiological research, the data are at the level of portion number and food weight. With sensitivity to the needs of practitioners in their offices and the population at large to gather more control over the keys to health-promoting behavior, demystification of the mathematical and chemical features of dietary recommendations could be made to achieve the goal of greater accessibility and empowerment for the public. This experience reveals, however, that the point of origin for this would be in the original epidemiological information used to find associations, and not in the back-calculation from a system that is intrinsically based on the denominator of total energy intake.

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# **PAHO Regional Consultation of the Americas on Diet, Physical Activity and Health**

Enrique R. Jacoby, guest editor

## **A call to action**

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In May 2002, 191 Member States of the World Health Organization (WHO) mandated that action be taken to develop a global strategy on diet, physical activity, and health (WHO/GS) to guide future efforts and resources in addressing the burgeoning problem of noncommunicable diseases worldwide. To that end, the Pan American Health Organization (PAHO) convened a regional meeting in Costa Rica on April 23–24, 2003. Delegates from 11 countries were in attendance, along with representatives of multisectoral institutions, nongovernmental organizations, and expert members of the scientific community.

In this brief introduction, I would like to address some issues before presenting the reader with a summary of the conclusions of the meeting. The issues are the magnitude of the epidemic of noncommunicable diseases, the key risk factors that need to be targeted and how best to deal with them, and the need for a common nutritional agenda attuned to the changing times.

### **The problem and the challenges**

The impetus of the WHO/GS was a result of recent data demonstrating that noncommunicable diseases and nonintentional injuries represent nearly 70% of all causes of death in the Region of the Americas among those 70 years of age and younger. The disability-adjusted life years (DALYs)\* lost to noncommunicable disease risk factors (high blood pressure and cholesterol levels, overweight, low intake of vegetables and fruits, and sedentary lifestyles) among the less developed countries in the region, excluding the United States and Canada, amounts to 12,458,000 DALYs added to the 4,677,000 DALYs lost to childhood and maternal undernutrition [1]. The repercussions of that situation on individuals and families are extraordinary, posing an even greater strain on already frail health-care systems, social services, and personal economic stability. Once thought to be “diseases of affluence,” noncommunica-

ble diseases are far-reaching and indiscriminate, and curing them is much more costly than curing common infectious diseases. All of these factors have contributed during the last decade to create a greater attention to preventive strategies. This is the new challenge to public health in the Americas [2].

Inadequate diets, physical inactivity, and tobacco use are the key health risk factors that account for most noncommunicable diseases and mortality. Thus, targeting those three behaviors is likely to yield better health results than emphasizing a disease-specific preventive approach. This concept was emphasized throughout the Consultation and is probably the most sensible strategy at hand. As was pointed out elsewhere [3], most patterns of unhealthy behaviors are set by the more affluent sectors of society, later to spread and cluster among the poorest. Economic, market, and cultural dynamics are powerful forces in shaping that process, and therefore they must be addressed to achieve the desired behavioral changes (see the report by Nugent [4] in this issue for an in-depth examination of the agricultural ramifications of the noncommunicable diseases issue). For health-conscious individuals, generally in the upper echelons of society, health literacy may suffice, provided material resources and time are plenty. For most that is not the case.

Successful public health interventions have to come to grips with the fact that eating and physical activity are human behaviors that respond to a variety of factors, not just to good information. In fact, individuals generally consider health as just one among many other factors when deciding what to eat and whether to exercise or quit smoking. For instance, in considering whether to make the choice of eating more fruits because that will bring health some 10 years down the road, many other competing factors are at stake. Serious competitors are notably short-term ones, such as convenience, immediate reward, time availability, and price, to cite just a few [5]. This is why public health strategists need to take into account all factors that influence key human behaviors, not only those associated with health motives.

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\* One DALY is equal to the loss of one healthy life year.

Child nutrition and maternal health are also vital to a long and healthy life. Thus, efforts to promote optimal women's diet and nutrition, healthy pregnancies, exclusive breastfeeding, and adequate complementary feeding not only are the foundation of optimal child growth and development, but also are key to promoting a long life free of noncommunicable diseases. This shows not only a clear convergence of objectives, but also that the underlying nutritional principle is similar: diet quality. In fact, for instance, undernutrition problems in the region focus on several micronutrient deficiencies leading to stunted growth, iron-deficiency anemia, low levels of vitamin A, and women's reproductive risk due to low folic acid levels. Likewise, dietary quality is crucial to preventing nutrition-related chronic diseases, such as cardiovascular disease, diabetes, and obesity.

If a life-cycle perspective is to be adopted, then optimal growth must be emphasized over gaining weight exclusively. By the same token, the age-old concept that a chubby child is a healthy child needs to be reconsidered as a gauge of health and a guide to child-feeding. Alarming escalating rates of obesity in children and adolescents require prompt action on this front. In children as well as in adults, it seems that merely quenching hunger will not necessarily carry health along.

## Main conclusions of the working groups

The following is a summary of the regional consultation's two working group discussions and conclusions. Those interested in reviewing complete transcripts of the working group conclusions can obtain a copy upon request to the author.

### Diet and nutrition working group

*Inadequate diet of the population.* In developed and developing countries of the Americas, the available data show an overall low and decreasing level of consumption of fruits, vegetables, whole grains, cereals, and legumes, while the consumption of foods rich in saturated fat and sugar, oils, and meats is on the rise. As Uauy and Monteiro note in this issue [6], those dietary changes are to a large extent supply-driven. The authors argue that the lower price of food as compared with most other commodities, such as education, health, clothing, and communications, coupled with new marketing strategies, has contributed to the aforementioned dietary changes. Priority actions to improve the quality of the population food supply are the development of policies aimed at increasing availability of and access to healthful unprocessed foods; reduction of salt, sugar, and saturated fat in processed foods; and substantial intersectoral collaboration at the national and international level, particularly among health, agricultural, educational, and regulatory organizations.

*Inadequate understanding of the problem and lack of public health leadership.* There is a preconception that most national public health systems and public health authorities remain unaware of the problem that elevated rates of noncommunicable diseases pose in the region, namely, the high burden of morbidity and mortality that is associated with them. The disproportionate toll of noncommunicable diseases on poorer populations has many negative social and economic consequences. In order to reverse this current situation, it was deemed a necessity to publicly call attention to the catastrophic impact of inaction; hence, the role of WHO and PAHO was perceived as crucial.

*Health services should include diet- and health-promotion activities.* Most health personnel are far from being active promoters of healthy dietary habits. Specialization and curative approaches are pervasive in most professional training and supported in health systems. Interaction with patients increasingly requires a more integrated approach to behavioral change than mere transmission of health information. The group called for a reorientation of health-care services to provide greater emphasis on disease prevention. Health-care providers should be trained to assess and counsel patients on disease-prevention behaviors, such as improved diet, regular physical activity, and smoking cessation, rather than on disease-specific prevention. Similarly, current nutritional programs aimed at children and women of childbearing age can improve their medium- and long-term health outcomes by focusing on children's growth and development, and by emphasizing quality over quantity in existing nutritional programs and national dietary guidelines.

*Better information to the public.* In a world saturated with food advertising that more often than not promotes unhealthy dietary habits or makes unfounded beneficial health claims, effective food labeling is recognized as an important resource to consumers. It was also considered necessary that public health systems more often and more consistently employ mass media approaches to develop health literacy. Finally, regulation of advertising was suggested as an option to protect consumers, particularly children.

### Physical activity working group

*A new paradigm in physical activity promotion.* Today the key public health recommendation for preventing or delaying morbidity and mortality is to accumulate a minimum of 30 minutes of moderate physical activity throughout the day, on most days of the week. This recommendation has been well established in the scientific literature and goes well beyond the practice of vigorous sports and aerobics to include more moderate activities such as walking, climbing stairs, dancing, or bicycling, which can be easily incorporated into the daily routine. Health professionals should play an active role

in explaining and promoting the adoption of the new physical activity recommendations.

*Public policies and environments for active lifestyles.* A successful promotion of an active lifestyle requires more than the best possible public information program. There is a need to establish public policies and norms, in conjunction with environments that enable individuals to remain active for life. Some examples are effective physical education programs in the schools, community walking clubs, good public transportation systems that include rapid motor transportation, encouragement of bicycling and walking, and policies to control crime on the streets.

*Multisectoral alliances.* The diversity of actions needed to promote physical activity, such as those listed above, requires multidisciplinary as well as multisectoral interventions. Thus, public health efforts should incorporate vital partnerships and alliances with sectors such as transportation, education, local governments, and sports, as well as private industry and nongovernmental organizations. Sometimes the actions of different players converge in practice, although their motives or objectives are not necessarily identical. The

ability to walk peacefully from work to home without running the risk of being mugged is an aspect of quality of life to one person, crime control to others, and physical activity to many in this Consultation.

*Role of the health and education sectors in the promotion of physical activity.* Disease prevention is now accepted as the most cost-effective way to tackle the epidemic of noncommunicable diseases. Thus, health-promotion activities ought to be part of the health provider's counseling repertoire. Hence, the training of health professionals and the norms of clinical management must reflect the proposed changes in professional practice. Likewise, the education sector has an enormous potential to instill healthy habits of entire generations, provided they keep physical education programs and other health-promotion activities alive and in good shape.

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# The challenge of improving food and nutrition in Latin America

Ricardo Uauy and Carlos Augusto Monteiro

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## Abstract

*The Latin American Region has exhibited a marked increase in the consumption of high-energy-density foods (high in fats and sugars) and a decrease in physical activity, with rising trends of sedentary life among the urban population. Social and economic progress led to a decline in infectious diseases, while higher income fostered the consumption of meats, fats and oils, and sugar and reduced the consumption of grains and legumes. The result has been a gradual increase in life expectancy at birth and a greater burden of disease linked to obesity and other nutrition-related chronic diseases (diabetes, cardiovascular disease, certain types of cancer, and osteoporosis). The region is currently facing the challenge of a double disease burden—the unresolved problem of malnutrition caused by nutritional deficits on the one hand, and the steady increase in chronic disease on the other. The need to develop policies and programs that make the healthy choice the easy choice in terms of diet and physical activity is presented. These should encompass not only individual choices, but also environmental factors that condition food and physical activity behavior. Food supply, and hence consumption, is largely driven by the productivity of the food-production chain; demand and consumption are determined by the way food is produced, processed, distributed, marketed, and advertised. These factors are beyond the consumer's control, and they oper-*

*ate to maximize profit, not health. Public health policies should focus not only on the demand side, but also on the supply of more healthful food products. Examples of potential interventions to increase the demand for healthful foods and the supply of healthier choices are presented and discussed.*

**Key words:** Chronic disease, diet, nutrition, policy, prevention

## Introduction

The “nutritional transition” is defined as changes in the food and nutrition profile of populations as a result of the interaction between economic, demographic, environmental, and cultural factors in society [1]. Nutritional patterns have changed in the Latin American Region, marked by an increase in the consumption of high-energy-density foods (high in fats and sugars) and a decrease in physical activity, with sedentary urban populations predominating [2–10]. Social and economic progress has improved environmental sanitation, contributing to a decline in infectious diseases. At the same time, higher income has fostered the consumption of high-energy-density foods and reduced the consumption of grains, legumes, and other sources of fiber. The result has been a gradual increase in life expectancy at birth and a greater proportion of obesity and other nutrition-related chronic diseases (type 2 diabetes, cardiovascular disease, certain types of cancer, and osteoporosis) in the total burden of disease. Latin America is currently facing the challenge of a double disease burden, dealing with the unresolved problem of malnutrition caused by nutritional deficits on the one hand, and facing a steady increase in nutrition-related chronic diseases on the other. In the majority of the countries, the transition toward the predominance of nutrition-related chronic diseases is in an advanced stage [4, 8–11].

The greatest challenge to health in the region,

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Mention of the names of firms and commercial products does not imply endorsement by the United Nations University.

according to recent statements by the World Health Organization (WHO) [4, 7, 10, 11], is the premature death and physical and mental disability resulting from chronic noncommunicable diseases. WHO has recently begun to examine the importance of the links between diet, physical activity, and nutrition-related chronic diseases—especially obesity, diabetes, cardiovascular disease, certain types of cancer, and osteoporosis. Worldwide and in Latin America, infant mortality has been on the decline, while the proportion of deaths from cardiovascular disease and cancer is rising and deaths from respiratory illnesses and infections are dropping sharply. In several Latin American countries, the age-adjusted rates for heart attacks and cancer are comparable to the figures found in a developed country such as Canada, while the rates of diabetes and stroke tend to be higher [2, 8].

Until recently, it was commonly thought that these chronic diseases were associated with excess—that is, with a wealthy environment. Another theory is that differences between countries are due to differences in genetic susceptibility, which would lead to the conclusion that this is a problem for individuals and almost a necessary evil or, even worse, a sign of social and economic progress. The reality in Latin American cities is that nutritional problems associated with nutritional imbalances, especially the imbalance between energy intake and energy expenditure, are most frequently observed in poor urban populations [2, 3, 5]. Changes in diet and physical activity can explain most of the increase in nutrition-related chronic diseases, which have reached epidemic proportions in many countries in recent decades. Clearly, this is the result of environmental changes, since genetic drift occurs over longer periods. What is certain is that our current genes were selected over the six million years of our species' evolution to maximize the use of ingested energy and store as much of it as possible for when it is needed. Today, in an environment that no longer demands physical labor to produce a little food, these same genes help to produce obesity, insulin resistance, and the associated metabolic consequences: diabetes, dyslipidemia, atherosclerosis, and hypertension.

Furthermore, according to the traditional medical model, nutrition-related chronic diseases are diseases associated with personal responsibility. This view emphasizes the identification of risk factors for each individual, which leads to an emphasis on a curative approach rather than primary prevention as the principal public health measure. Most developing countries presently do not have the means to provide effective care for all people at risk and are used to planning only for the short-term situation. The steady increase in life expectancy and in the proportion of the population over 65 years of age clearly indicates the need for Latin American countries to steadily increase their health expenditure for the prevention of nutrition-related

chronic diseases. For most countries in the region, curative approaches are simply not compatible with the economic resources at their disposal. Latin America is aging before having reached an income level that will allow for adequate expenditure to provide for basic health care and treatment for the diseases of adults and the elderly. Unlike the developed countries, which managed to achieve economic well-being side by side with an increase in life expectancy and today spend from US\$2,000 to 4,000 per capita annually on health, the region does not have the resources to provide adequate curative care. Even if these funds were available, the outlays would be greater than the total per capita income of many countries in the region. It would be far more effective to control and prevent nutrition-related chronic diseases at a population level than to place emphasis on individual treatment [10].

Economic growth, so necessary to secure the material and human resources needed to combat nutritional deficiencies, can have adverse effects on health, since it can heighten the risk of nutrition-related chronic diseases, especially in transitional societies. Economic growth in these societies is associated with environmental changes that lead to unhealthy diets and sedentary lives. From the nutritional standpoint, we should note the increase in the availability of foods of animal origin, which are high in saturated fat, and of processed foods, which are usually rich in fats and sugar and low in fiber—that is, high-energy-density foods. Physical activity patterns change, since the technological development that accompanies economic growth reduces the physical labor required in urban and rural occupations alike, reducing daily energy expenditure. Economic growth leads to changes in diet that can neutralize or even reverse the relative protection against nutrition-related chronic diseases afforded by the traditional diets of the poorer population sectors. This is because the poorer sectors are more likely to change their eating and physical activity patterns, either because they do not have the knowledge required to resist the adverse changes in the environment, or because they lack the material conditions required to make use of this knowledge. Clearly, we are talking about the potential, not the inevitable, consequences of economic growth for nutrition-related chronic diseases. The important thing is to remember that it is perfectly possible to avoid these consequences through public policies and education and health-promotion strategies.

Traditional diets, based on primary foods with little processing except for the traditional methods of preservation (e.g., solar drying or dehydration, fermentation, and salting), are predominantly found in rural areas. Urbanization is often associated with the abandonment of traditional diets and their replacement with an urban dietary culture. The rural diet, based largely on vegetable products with small quantities of foods of animal origin, stands in contrast to the typical Western urban

diet with regard to the different quantity and quality of fat that it contains, the virtual absence of sugar or other refined carbohydrates except honey or dried fruits, and its higher fiber content. In several parts of the region—for example, northern Mexico—there is evidence of a dramatic increase in obesity and diabetes among indigenous populations who abandon their traditional diets in favor of the Western diet, with serious consequences for health [5, 7]. Likewise, on migrating to the cities and increasing their income, people from rural areas of the region tend to become less physically active and to adopt a diet rich in high-energy-density foods loaded with fat and sugar, frequenting fast-food restaurants that encourage overeating, with an increase in the prevalence of nutrition-related chronic diseases. Urbanization, however, also favors a more diversified diet with higher nutrient density, since today's market offers a wide variety of food all year round. The urbanization process by itself is not responsible for its negative consequences; it is possible that, with educational support and the promotion of healthy eating, the urban dietary culture will make a better diet possible. Urban sprawl around the major cities, which contain 20% to 40% of the population of their countries, has been a powerful force that alters all the components of the food-production chain. Urbanization certainly has major implications for the distribution and final marketing of food, and ultimately for dietary intake. Urban areas have facilitated the gradual concentration of delivery systems in fewer and fewer hands. They have also promoted the proliferation of mega-supermarkets to the detriment of the small corner markets in every neighborhood that were once the norm in food distribution. The concentration on intensive crop production has led to the disappearance of small producers who cannot compete with major agroindustrial conglomerates in either productivity or prices [12–14]. At the transnational level, the liberalization of trade has facilitated the penetration of Latin American markets by large multinational companies.

### Changes in the demand for food

A review of the changes in food availability in the countries of the region, based on information compiled by the Food and Agriculture Organization (FAO)[15], shows that energy availability has increased in almost every country except Cuba. The same increasing trend is also seen for the proportion of total calories obtained from fat. In practically all countries, the percentage of calories obtained from fat now exceeds 20%. These averages mask huge inequalities produced mainly by differences in income, so that after correction for the corresponding elasticities, it can be seen that a significant proportion of the population in several countries consumes a diet with more than the recommended

maximum of 30% of calories from fat. The percentage of calories obtained from protein has not changed, ranging from 10% to 12%, which is consistent with adequate intake and a diet sufficient in proteins. In fact, protein malnutrition in the region is uncommon, except in young children who suffer from repeated infections and inadequate supplementary feeding and who are living in environments characterized by extreme poverty or marginality [9, 10].

There has been a marked increase in the availability of animal protein in the region, led by poultry consumption, which has grown by five to six times in most countries. The consumption of red meat has held steady, except for a decline in Argentina and a marked increase in Brazil and Chile, although Argentina continues to consume two to three times more meat than the other countries of the region. There has been a significant rise in the consumption of whole milk, while seafood consumption is low in virtually all the countries of the region. The per capita consumption of vegetable oils has increased by 200% to 300% in most countries. At the same time, the consumption of refined sugar has almost doubled in some countries. On examining fruit consumption, we see that the figures are relatively high, on average, for nearly all countries, but vegetable consumption is low except in Argentina and Chile. The recommendation to consume at least 400 g of fruits and vegetables implies a total of 160 kg per capita annually. The information from the FAO indicates that few countries in the region reach that minimum goal [10, 11, 15]. Finally, if we examine the consumption of grains such as wheat and corn, we see the importance of these two grains for the region, and a clear preponderance of corn in Mexico and wheat in Argentina and Chile.

Income is the main determinant of the availability of and demand for food. This is evident from the FAO data on the different countries and regions. The higher the income, the greater the availability of energy, the higher the consumption of animal products (meat and dairy products), and the lower the consumption of grains and complex carbohydrates. The amount of sugar, total fat, and animal fat consumed also increases as earnings increase, leading to a diet of higher energy density. The reduction in the intake of fiber and vegetables completes a dietary pattern that, in conjunction with physical inactivity, promotes nutrition-related chronic diseases.

Very few countries in the region conduct periodic surveys of real food consumption. Mexico is a notable exception [5]. The consumption trends extrapolated from real food-consumption surveys are of great value, since they bear a direct relation to the risks of nutritional disorders. The trends from the consumption surveys in the region are compatible with the trends observed in the data on availability. However, the consumption surveys make it possible to examine

differences between regions or special groups due to their vulnerability. The Mexican data show a significant increase in the intake of calories from fat in the northern part of the country and low levels of intake in the south. Viewed as an average, the figure is reasonable, since the inadequacies stemming from excess or deficit cancel each other.

The data from the household expenditure surveys that some countries conduct to determine the number of poor people in their population provide valuable information on the impact of income on the relative weight of the different components of household expenditure. Thus, the higher the income, the lower the percentage of income spent on food; this percentage is often used to determine the level of poverty in a population. In general, a poor household is defined as one in which 50% or more of its income is spent to purchase the basic food basket for a typical family. Higher-income households, in contrast, spend no more than 12% to 15% of their income on food.

The data from these surveys do not allow us to assess individual consumption or dietary adaptation, unless we apply the information to a typical family. However, they do allow us to examine the priority that the poorest and wealthiest families assign to the components of food expenditure [2, 5, 16]. If we divide households by income, we will find that in many countries, lower-income households do not give priority in their purchases to the amount of nutrients in the food, but to the symbolic value linked to what is socially acceptable. The purchase of soft drinks and of sweet and salty fatty snacks is given priority over that of fruits and vegetables or milk. The preferred products are those promoted in the mass media, which generally contribute calories and little else. Higher-income households increase their food expenditures outside the home, and meats and other animal products are heavily represented, with a relative decline in the weight of grains and oil. In general, the data show major differences in the consumption of the foods that are most expensive and denser in specific nutrients. The poor have monotonous diets that meet or exceed their energy needs but are deficient in vitamins and minerals, especially iron, zinc, vitamins A and C, and folate.

The impact of income on expenditures for certain foods can be quantified by measuring changes in expenditure by type of food when income increases by 1%. This index is known as expenditure elasticity. Data from household expenditure surveys in the United States demonstrate that for low-income families, the expenditure elasticity for meat and dairy products is on the order of 0.6 to 0.8, while for the wealthiest, this index is from 0.3 to 0.4 [13, 17, 18]. That is, as their income increases, poorer households increase their spending on foods of animal origin in greater proportion than do the wealthiest households. Elasticity values are lower for grains, and in the case of higher-income

families, they can become negative—that is, when earnings increase, grain consumption decreases. There is no doubt that increasing income is positive, since it enables families to diversify their diet, but unless eating habits and physical activity levels are modified to preserve the balance between energy expenditure and energy intake, the consequences for health can be adverse.

Access to food is also a function of prices. For a given income-level group, the expectation is that the prices of foods in high demand will rise, while those of foods in lower demand will fall. This is the law of supply and demand, a basic law of economics. The law holds true with certain foods, such as seasonal fruits, which are expensive at the beginning of the season and become less so as the days or weeks go by. However, recent trends for some foods, such as vegetable oils and sugary soft drinks, indicate just the opposite: as demand rises, their prices drop because of the greater volume of production and hence consumption. In this case, the higher demand is offset by greater supply, and thus unit prices fall while the volume of production increases. Producers therefore lower their profit per calorie but increase their sales volume to more than compensate for this. The forces of the market thus push for an increase in consumption, even though it leads to a lower unit price, which is compensated by delivering and marketing the product in larger-volume containers. For example, in the case of fast food, higher consumption leads to the optimization of production systems, thus lowering the unit price, which is compensated for by a higher volume of product per serving. If to this we add fat, salt, sugar, and coloring to make the food more attractive and enhance the flavor, we have the foundations for the overconsumption of high-energy-density, sweet and salty fatty foods. The consumer is offered more product for less money, and the system that regulates the appetite is not prepared to resist the temptation.

Data from the United States indicate that at least 40% of the increase in the prevalence of obesity over the past 25 years is due to the reduction of the unit price of food, especially of sweet and salty fatty snacks [13, 16, 17, 19, 20]. There is no doubt that increased livestock productivity has made it possible to free us from hunger, but along with this come new risks to health and some threats to the environment. We should be able to maximize the benefits and minimize the risks posed by advances in technology, with the object not only of securing higher consumption at lower prices, but also of minimizing the risks, including the impact of these production processes on the environment and human health [7, 16, 21]. Our inability to modify individual behavior by increasing physical activity and decreasing intake is predictable. Unless we examine the underlying causes of our food preferences and our physical activity habits, we will not be successful in controlling this epidemic. Policies such as direct sub-

sidies, price regulation, and food advertising also play an important part in shaping consumption patterns, as we will see further on [7, 13, 21].

## What drives food choices?

It is normally believed that food choices depend essentially on the law of supply and demand. Thus, the consumer's preference is the basis of the demand and determines the supply. This model places consumers as the principal driver of supply, with industry merely meeting their needs. In this case, the factors that usually determine food purchases and consumption patterns are the consumer's income, the prices, and the intrinsic and perceived quality of the products.

A more in-depth analysis of what drives consumption reveals that nowadays supply does not passively wait to respond to demand but has a life of its own and actively influences the choice of goods for purchase and consumption. That is, we buy and consume what is offered to us, not what we need to live a healthy life. What drives supply, and hence consumption, today is largely dominated by the factors that determine the productivity and profits of the food-production chain. In this model, demand and consumption are determined by the ways we produce, process, distribute, trade, market, and advertise food. All these factors are beyond the consumer's control, and they operate mainly on the maximization of profit. The food-production chain responds to the need to produce progressively cheaper food and promote the highest possible consumption. As evidenced daily in the press, the eagerness to maximize profits creates both advantages and risks. The possibility of producing safe and less expensive food is no doubt the greatest advantage. However, the risk of ignoring concerns about a safe and healthy diet is also inherent in a model that puts commercial interests above consumer health. Some say that the responsibility for resolving this dilemma lies with the consumer, and that it is enough to provide information through nutritional labeling, public service announcements about healthy eating, or nutritional guidelines that promote healthy eating. What is certain is that the food-production chain and the engines that drive the food supply are very powerful, and they do not have a real counterpart in the efforts to educate, guide, and facilitate the selection and consumption of safe, wholesome food by the consumer [7, 10, 11, 13, 16, 19–21].

In this battle the consumer is David, since the forces that drive supply are largely invisible and unidentifiable, and have powerful resources that motivate and determine consumer behavior. Thus, we enter a restaurant or eatery, attracted by an environment that for a few minutes makes us feel like members of the "first world" and as good as anybody else—an environment

with a little luxury that sparkles like the stars, where each piece of furniture, container, and product is an icon that in some way symbolizes our aspirations for success, where our ancestral hunger for sweet, salty, and fatty foods is whetted with tempting offers of more food for less money, a double portion for a few cents more, buy two and get one free, buy an A + B + C combination meal for a moderate price and experience bliss in this paradise of consumption for the sake of fun and instant gratification. The dilemma of personal responsibility coupled with an environment that encourages healthy eating and an active life versus an environment that can discourage healthy food choices and promote a sedentary life is illustrated in figure 1. Certainly, we can help our consumers in the uphill battle against environmental influences, but we will be much more successful if at the same time we can make the hill less steep by promoting changes in the environment that will make the healthy choice the easy choice.

## What can public policies do?

Public policies can modify the way the supply of food influences consumption patterns and health; we provide below some examples of possible interventions.

» *Optimize the food-production chain to offer more healthful products at lower prices for poor consumers.* The private sector has introduced technology to improve agricultural production, concentrating on a few crops with greater potential added value for exports. Improving the marketing of fruits and vegetables and decreasing the number of middlemen can help raise consumption levels among low-income groups, preserve and support small farmers' produce markets in Latin American cities,



FIG. 1. Helping individuals carry the burden versus lowering the slope to make the load lighter. Graphic representation of individual responsibility of consumers in making healthy choices in terms of diet and physical activity, as illustrated by the man pushing a large rock up the hill. We can certainly support his effort by health-promotion and educational programs, but we can achieve even more if at the same time we make the slope less steep by changes in the environment that support the consumption of healthy diets and active living

and promote healthful and safe food production.

- » *Eliminate subsidies and economic incentives for the production of foods rich in saturated fats and facilitate the production of foods low in animal fat.* Several countries provide incentives for milk and meat production through subsidies or price-setting that favors producers. In some countries, the quality regulations require higher prices for meat and milk with a higher fat content, which has a clear impact on the supply of these products. Furthermore, at the point of sale, skimmed milk and lean meats are more expensive. An alternative policy that would benefit health would be to equalize skim and whole milk prices, along with the prices of lean and fatty meats. These changes would shift the incentives and benefits from the large producers to the consumers, bearing in mind that the economic benefits of achieving healthier eating patterns are more than compensated by the subsidies that producers may currently be receiving.
- » *Review the regulations governing the international food trade from a nutritional and health perspective.* Today, it is acceptable to impose trade barriers for phytosanitary reasons—that is, when products can pose a threat to animal or plant health. The Codex Alimentarius has provisions governing the chemical and microbiological safety of foods. However, except for baby formulas, there are no restrictions on international trade in products that can affect human health; thus, countries that produce a milk surplus and have a higher consumption of skimmed milk generate a surplus of milk fat that they market in the developing world at low cost, with harmful consequences for sedentary urban populations. Here, the economic benefits of a free market should be balanced against the economic costs of an unhealthy diet's impact on health.
- » *Review the regulations governing the institutional food offered in schools, public utilities, the armed forces, and the workplace.* Institutional food programs financed with public moneys in the countries of the region do not meet the standards of a healthy diet. An effort should be made to determine whether the food provided in institutions contains the right quantity and quality of fats, promote the recommended consumption of fruits and vegetables, and foster healthy eating habits. This is a matter of great importance. When commercial interests prevail, institutions tend to install vending machines filled with high-energy-density foods (sweet and salty fatty snacks and beverages with little or no nutritional value).

Public policies can work also at the demand side, and we provide below examples of interventions to increase the demand for healthful foods.

- » *Increase the relative prices of unhealthy foods.* The laws of economics indicate that the higher the price, the lower the consumption. It is a hard thing to say

that food should be subject to these policies, but at the very least we can make healthier food choices less expensive. In some countries, for example, fast-food restaurants that sell the usual foods loaded with saturated or hydrogenated fats must also offer salads or fruit at the same price to encourage the healthier option. That is, for the price of a hamburger with French fries, customers should have the option of substituting a salad for the fries. In other cases, the prices of skim and whole milk have been equalized.

- » *Facilitate the selection and consumption of healthful foods at lower prices.* Information on the experiences of several countries in the region in how to select the best nutrition at the lowest possible price, based on the composition of local foods and prices at a given time, can be disseminated with software to assist groups or families in this process. PLANUT (PAHO) and Best Purchase in Peru are examples of such efforts. Combining this strategy with consumer cooperatives formed to obtain better food prices and better quality will create a powerful tool for promoting a safe and healthy diet for the consumers who most need it.
- » *Provide consumer information at the point of purchase.* Evaluations of the use of nutritional guidelines and nutritional labeling as a tool for promoting a healthy diet reveal significant limitations, especially the limited effectiveness of these strategies in modifying consumption patterns. Providing information at the point of purchase through consumer educators, attractive handouts, and icons to indicate healthful foods is more effective. Recent assessment of an activity in Chile shows that giving consumers information at the point of purchase has significant potential for influencing food choices.

Table 1 illustrates policy instruments and activities that can be applied at different stages of the food-production chain to reduce saturated fat intake, as well as its potential impact on consumption. We have spoken about intervening in the food-production chain. In many cases, this will affect the powerful economic interests of the producers or marketers of certain products. These groups represent not only economic but also political power, which implies a potential conflict that must be addressed taking the public interest into account. These issues must be debated throughout society, and it is the political rules of the democratic process that must determine how to protect community interests. Here, the press and opinion makers have a key role to play. In a democratic system, the state and governments are the ultimate guarantors of community well-being. They are elected for this purpose and must be accountable for the policies implemented to promote the health of the population. Citizens and those who help to shape public opinion must play a key role in demanding and ensuring safe and healthful food as a basic right. The Latin American Region should not

TABLE 1. Potential supply- and demand-side interventions in the food production chain to modify food consumption, for example, in this case to reduce saturated fat intake

Link in the food-production chain	Food policy instruments with nutritional impact	Examples of impact on fat consumption affecting quantity or quality of fat intake	Effectiveness in reducing intake of saturated fat
Food production	Subsidies or price supports	Subsidies for feed production Support for dairy products; price guarantees for producers	Very negative Very negative
	Import and export quotas	Export incentives for vegetable oil Restrictions and/or tariffs on meat imports	Uncertain Uncertain
Food processing	Quality grading	Definition of the level of quality (changes in the criteria for selecting quality, e.g., lean versus fatty)	Very positive
	“Identity standards”	“Identity standards—switch to low-fat milk and yogurt”	Positive
	Nutrition labeling	Descriptors in nutrition labeling (e.g., low-fat milk, ice cream)	Very positive
Distribution, marketing, and advertising of food	Advertising campaigns for dairy products	Changes in the demand of Government programs for milk products (low-fat to replace full-fat milk)	Negative
	Nutrition labeling	Use % lean in the labeling of ground meat Labeling in restaurant menus to indicate the quantity and quality of fat, low in saturated fat	Negative Positive
	Marketing standards	Need for standardization of the various sector descriptors: agricultural, health, trade	Uncertain
Food choices and consumption	Nutrition labeling	Label indicating the quantity and quality of fat	Very positive
	Public information campaigns to promote good nutrition	Nutritional guidelines for consumer orientation Icon to orient food choices (pyramid)	Very positive Very positive
	Promotion groups for specific products	Promotion of cheese, milk, meat, ice cream, eggs	Very negative

Source: modified from ref. 13.

only complete the task of eradicating hunger, but it should promote healthy diets and active living as a way to ensure optimal health and quality of life while reducing loss of healthy life years.

## Conclusions

Dietary patterns, nutrition, and the level of physical activity not only affect current health but determine the risk of developing nutrition-related chronic diseases in the future. These diet-related diseases are the leading cause of disability and death in the industrialized countries and in most of the developing countries. The prevalence of risk factors for nutrition-related chronic diseases is progressively increasing both in the developing countries and among the poorer populations of the industrialized countries. In Latin America, this risk also includes the legacy of early malnutrition, both in

the womb and after birth. Communities, regions, and countries that have undertaken integrated, nationwide mass interventions have managed to reduce risk factors and deaths from nutrition-related chronic diseases dramatically. Success has been possible when societies have come to understand that premature deaths from nutrition-related chronic diseases are mostly preventable, and when they have mobilized to demand that their political representatives create environments and institute public policies that promote and support healthy living. This has been achieved when governments, communities, and the private sector share the notion that laws and regulations should be changed to ensure that neighborhoods, schools, and the workplace promote and support the consumption of healthy diets and encourage the level of physical activity necessary to attain a healthy weight.

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# Promoting physical activity in the Americas

Michael Pratt, Enrique R. Jacoby, and Andrea Neiman

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## Abstract

*Physical inactivity, obesity, and noncommunicable disease rates are rapidly climbing to epidemic proportions and are becoming the leading causes of death and disability in the Americas and globally. The causes are complex and will require a multifaceted, multisectoral approach. Recognizing this, the World Health Organization adopted a broad-ranging process to develop a Global Strategy for the Promotion of Diet, Physical Activity, and Health, as mandated by the World Health Assembly in May 2002. The results of the yearlong effort are to be presented at the World Health Assembly in May 2004.*

**Key words:** physical activity, non-communicable diseases, Americas region, disease prevention, health promotion, policy

## Note from the guest editor

*This paper reports the efforts of the World Health Organization Regional Consultation on Diet and Physical Activity in the Americas. The authors' main concerns are the problem of physical inactivity at the population level, and how it can be addressed in order to improve health and quality of life. Although the rationale for promoting physical activity and the blueprint for doing*

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*so are clear, most national public health agendas in the region do not address the emerging problems posed by the epidemic of noncommunicable diseases, and the capacity to develop, target, implement, and evaluate programs is limited. Strengthening capacity and providing training for policy development, surveillance, evaluation, and partnership building is essential for effective physical activity promotion and disease prevention. These major challenges confront public health practitioners around the globe. They are especially salient in the Americas, where the epidemiologic transition to predominance of chronic diseases is coupled with rapid urbanization. However, the Americas also have an abundance of creative, community-based physical activity-promotion programs, a network linking these programs, and examples of cities transformed into environments friendly to pedestrian life and recreation. All of this is occurring against the backdrop of an unquestionable strong national and regional interest in physical activity and health.*

—Enrique R. Jacoby, M.D., M.P.H.

## Introduction

Physical inactivity, obesity, and noncommunicable diseases are rapidly climbing to epidemic proportions and are becoming the leading causes of death and disability in the Americas [1]. This is of concern because inactivity and obesity are no longer seen as by-products of affluence, but are now a phenomenon increasingly observed among middle- and low-income groups in developing countries [2]. It is widely recognized that energy- and fat-rich diets, inactivity, and smoking underlie the epidemic of noncommunicable diseases. Much greater focus is now being directed toward understanding why individuals choose poor diets and lead sedentary lifestyles, and how modern environments and public policies may influence those choices. It is clear that in order to design effective interventions for inactivity, poor diet, and obesity, a broad, multisectoral approach, incorporating a variety of strategies and partners, will be required.

In this paper we are mainly concerned with the problem of physical inactivity at the population level, and how it can be addressed in order to improve health and quality of life. We will address eight major questions in the paper and in the regional consultation:

- » Why is physical inactivity a critical public health issue in the Americas?
- » What are the health and associated social benefits of regular physical activity?
- » How much physical activity is recommended for health?
- » How physically active are adults and children in the Americas?
- » What are the most important individual, social, and environmental determinants of physical activity?
- » What strategies and interventions have proven to be effective in increasing population levels of physical activity?
- » What are the components of a national physical activity policy, and how can they be effectively implemented?
- » What are some examples of successful programs for promoting physical activity in the Americas?

## A critical public health issue

Physical inactivity has become a major public health problem throughout the Region of the Americas, for several reasons. First, the prevalence of inactivity has markedly risen over the last half century as urbanization, motor transportation, computerization, communications technology, and increasingly sedentary jobs and pastimes have more than counterbalanced an apparent increase in leisure time or recreational physical activity [3, 4]. Second, physical inactivity is an important risk factor for obesity, cardiovascular disease, colon and breast cancer, and diabetes [5]. These noncommunicable diseases, formerly associated with high-income populations, now account for a large share of total morbidity and mortality across every socioeconomic group in almost every country in the Region of the Americas [6]. It is estimated that in the United States, physical inactivity and poor diet account for at least 14% of all deaths [7], and globally, inactivity accounts for more than two million deaths annually [8]. Physical inactivity also has substantial economic costs. Analyses from Australia, Canada, the United States, São Paulo State in Brazil, and Switzerland indicate that physical inactivity is responsible for 2% to 6% of total health-care expenditures [2]. In the United States, this represents as much as \$76 billion annually in potentially avoidable health-care expenditures [9]. Lastly, effective interventions exist to increase population-level physical activity. Thus, physical inactivity is a classic public health problem: large amounts of disease are attributable to inactivity, a majority of the

population is at risk, and effective strategies to address the problem exist.

The role of physical inactivity in the current global obesity epidemic is of special interest. Obesity is a consequence of positive energy balance, resulting from a combination of excess energy consumption and diminished energy expenditure. Almost a century ago, a worldwide phenomenon of increases in secular weight and height began to gain attention, but it was only recently that obesity emerged on a global scale [10]. Powerful societal and environmental forces may have contributed to shape our physical activity patterns and diets; among them, the unprecedented surplus and declining real price of food, urbanization, motor transportation, and increasingly sedentary jobs and pastimes [3].

Recent economic studies highlight the fact that technological change has both raised the cost of physical activity and lowered the cost of calories. Cheap, available food, rich in energy and high in saturated fat, coupled with labor-saving technology in the workplace, leads us toward progressively more sedentary lifestyles, facilitating an economic environment that favors weight gain [3]. Many people were formerly employed in jobs that required significant caloric expenditure, but today fewer and fewer jobs require regular physical activity. For most persons of middle and upper socioeconomic classes, participation in physical activity often requires an expenditure of both time and money for equipment or facilities [3, 9].

## Health benefits of physical activity

At the root of the multiple health benefits associated with physical activity are the many physiologic and metabolic responses. Physical activity requires increased energy expenditure and imposes demands and stresses on multiple organ and enzyme systems. These demands lead to acute and long-term responses of the circulatory, respiratory, nervous, endocrine, and skeletal systems. The most direct benefits of physical activity are cardiovascular and musculoskeletal adaptations, which increase functional capacity in these organ systems. Increased aerobic capacity and muscular strength and endurance have been well documented following training programs in individuals of all ages. Maintenance of functional capacity and strength is especially important for preventing disability and maintaining independence among older adults. Many disease- and risk factor-specific benefits of physical activity have also been identified in epidemiologic and clinical studies. Convincing data link regular physical activity to lower rates of coronary heart disease, diabetes, and colon and breast cancer, as well as to improvements in mental health, glucose metabolism, and bone density [11].

### Coronary heart disease

Epidemiologic studies over the past 50 years demonstrated that heart disease was less likely to develop in active railroad workers and in conductors on double-decker buses in London than in the less active drivers, and that among longshoremen, the most active men had the lowest risk of coronary heart disease [12]. Longitudinal studies of college alumni have shown a reduced incidence of coronary heart disease and lower mortality from coronary heart disease and from all causes among regularly active men as compared with their sedentary counterparts [13]. Previously sedentary men who initiated regular physical activity in middle age also reduced their risk of death from coronary heart disease and all-cause mortality when compared with men who remained sedentary [13]. Increased physical fitness has been linked with lower mortality from all causes and from coronary heart disease among both men and women. Overall, the risk of coronary heart disease in sedentary men is about twice that in men who are habitually active [14]. To date, no randomized clinical trial of physical activity for the primary prevention of coronary heart disease has been conducted. However, the association of regular physical activity with reduction in coronary heart disease meets strict epidemiologic criteria for causality: the association is strong, consistent, graded, temporally appropriate, and biologically plausible.

The evidence for regular physical activity in the secondary prevention of coronary heart disease is at least as strong as that for primary prevention. Patients with coronary heart disease who engage in regular physical activity as part of a cardiac rehabilitation program have lower mortality from all causes and from coronary heart disease than do nonparticipants one to three years after initial hospitalization. Exercise-based cardiac rehabilitation programs have also been shown to increase functional capacity and reduce coronary heart disease symptoms and may improve quality of life. Appropriate physical activity should be a part of the management and rehabilitation of most patients with coronary heart disease [15].

### Weight control

Individuals who are regularly active tend to weigh less and have a lower percentage of body fat than sedentary individuals, despite the fact that physically active persons are consistently observed to consume more calories than sedentary individuals. Regular physical activity increases caloric expenditure indirectly by raising the resting metabolic rate after activity, as well as directly by the activity itself. A combined program of diet and regular physical activity appears to be the most effective means of maintaining ideal body weight. Regular physical activity appears to alter body fat dis-

tribution beneficially, independently of its effects on body weight and total adiposity. The quantity of daily physical activity required to maintain body weight in the context of a modern, developed society is in debate. Although longitudinal data are lacking, recent reports suggest that as much as 60 minutes per day of moderate-intensity physical activity may be necessary to prevent weight gain [16, 17].

### Diabetes

Physical activity increases muscle glucose uptake directly and also increases insulin sensitivity. Physical activity is commonly prescribed for managing non-insulin-dependent diabetes mellitus (NIDDM). Physical activity may also prevent NIDDM through its effects on insulin and glucose metabolism and maintenance of body weight. In well-conducted longitudinal studies, the incidence of NIDDM has been observed to be lower in regularly active male college alumni, physicians, and female nurses than their sedentary counterparts [18].

### Osteoporosis

Physical activity may play an important role in maintaining bone mineral density, preventing osteoporosis, and reducing fractures. Bone density is reduced by bed rest and can be increased by weight-bearing activity. Regular physical activity has been demonstrated to increase bone mass in young women and reduce the decline in bone mass seen in postmenopausal women, and it may increase bone density in patients with osteoporosis. Postmenopausal women who walk approximately one mile per day have higher bone mineral density and slower rates of bone loss than do sedentary women. Regular physical activity also increases muscle mass and strength, perhaps reducing the risk of falls and protecting against fractures when falls do occur [5].

### Cancer

Both regular physical activity and physical fitness have been associated with lower mortality from cancer in longitudinal studies. Although data for most specific cancers are limited, studies of occupational and leisure-time activity indicate that physical activity is protective against colon cancer [19]. Several studies, and most of the more recent studies, suggest a reduced risk of breast cancer in regularly active women, but many earlier studies failed to demonstrate this relationship [5]. The protective effects may be mediated by reduced intestinal transit time (colon cancer) and altered endocrine function [20].

## Mental health

Regular physical activity and physical fitness are positively associated with mental health and well-being. Persons who are regularly active report less anxiety and depression and lower levels of stress than do sedentary persons. Exercise programs may be useful as adjunctive therapy for treating mild to moderate depression [21].

## Social benefits

Regular participation in physical activity has been shown to provide social benefits through enhanced social interaction and integration. Several studies suggest that individuals who are physically active are more likely to take an active part in their community, are less likely to withdraw from society, and have widened social networks. In addition, studies have shown that children and adolescents who are regularly active attain higher scholastic achievement and are less likely to be involved in drugs, alcohol, or other negative behaviors compared with adolescents and children who are not regularly active [8, 22].

## Physical activity recommendations

An important issue for public health policy is how much physical activity is required for significant health benefits. Very good epidemiologic and clinical research data indicate that substantial health benefits may be achieved with at least 30 minutes of daily physical activity of moderate intensity, such as brisk walking [5, 23]. Public health institutions in many countries around the world, including the World Health Organization (WHO) and the Centers for Disease Control and Prevention (CDC), have endorsed a recommendation of at least 30 minutes of moderate-intensity physical activity accumulated over the day in bouts of at least 10 minutes, on most days of the week [2, 5, 23]. Additional benefits may be obtained by most individuals if they participate in higher-intensity or longer-duration physical activity [5]. However, between half and three-quarters of most adult populations are sedentary or only minimally active, and the basic 30-minute recommendation poses enough of a challenge for this group [5, 6]. Recent reports from WHO and the US Institute of Medicine have specifically addressed the role of physical activity in preventing weight gain and obesity [8, 16, 24]. In spite of these efforts, the amount of physical activity needed to prevent weight gain is still in debate, and most probably varies considerably from person to person, in part because dietary intake varies considerably from person to person. However, it appears that persons who were previously obese may require more than 30 minutes of moderate-intensity

physical activity per day, usually 60 to 90 minutes, to maintain a healthy weight. [16, 24]

## Levels of physical activity and inactivity in the Americas

Physical activity occurs in five primary domains: transportation, recreation, domestic, occupational, and school. Physical activity levels in these domains have changed significantly in recent decades in many, if not most, countries in the Americas. Occupational physical activity has declined markedly with increased mechanization and computerization; domestic and transportation-related physical activity probably is declining; and leisure-time physical activity is increasing in at least some countries [4, 25]. The prevalence estimates for adult physical activity vary considerably, depending on how many domains are included within a given survey and how physical activity is defined [26]. When only leisure-time activity was included in a 1996-97 survey, 13% of adults in Brazil were categorized as regularly active [27]. By contrast, a more recent study of a representative population in the southern Brazilian city of Pelotas utilizing the short International Physical Activity Questionnaire (IPAQ), which assesses domestic, occupational, and transportation physical activity in addition to leisure-time activity, reported that 58.9% of adults were regularly active and 41.1% were inactive [28]. Similarly, in 2001, when the US Behavioral Risk Factor Surveillance System included physical activity from occupational, transportation, and recreational domains, the prevalence of regular physical activity reached 45.4% [26]. In most published studies from Latin America, physical inactivity, defined as no or very little recreational or sports-related physical activity, is reported in a form that allows at least some degree of comparison. Data from Chile [29], Peru [30], Argentina, Brazil, and a PAHO study of seven metropolitan areas in Latin America show adult prevalences of physical inactivity between 50% and 91% [25]. Although estimates of the prevalence of physical activity vary considerably due to varying definitions of physical activity and survey methods, the overall pattern of physical activity is quite similar across the Americas (fig. 1).

Taken together, these studies allow the following conclusions to be made:

- » More than two-thirds of adults in many countries in the Americas do not engage in sufficient regular physical activity to accrue significant health benefits
- » People of all ages lead inactive lifestyles
- » Physical activity decreases with age
- » Women tend to be more inactive than men [5, 26, 27]
- » Low-income and less-educated sectors participate in less sports and recreational physical activity but more

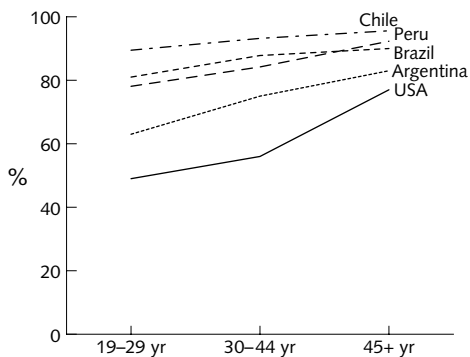


FIG. 1. Rates of low frequency of leisure-time physical activity (once a week or less) among adults in selected countries. Sources: Peru [31], Chile [32], Argentina [33], Brazil [27], United States [34]

occupational and transportation physical activity than higher-income or better-educated populations [26, 30] (fig. 2).

### Determinants of physical activity

A large number of demographic, biologic, psychological, cognitive, social and cultural, and environmental factors influence participation in physical activity [35]. The determinants of physical activity and inactivity are truly multifactorial and vary according to person, setting, and culture. The availability of time, facilities, and other material resources probably contributes to the higher participation in leisure-time physical activity of the more educated and wealthier segments of most populations. To reach less advantaged populations, it is important to expand our understanding of the determinants of inactivity beyond individual characteristics. It has become increasingly apparent that patterns of activity are a result of more than individual volition [36]. New research suggests that environmental vari-

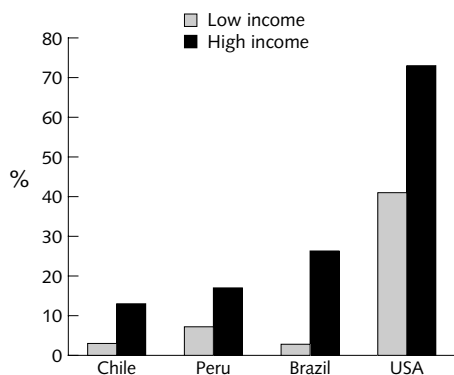


FIG. 2. Percentage of adult women engaged in leisure-time physical activity at least once a week according to income level and country. Sources: Peru [31], Chile [32], Brazil [27], United States [34]

ables, such as access to recreational space, neighborhood design, weather, and safety, contribute to patterns of inactivity [37].

Mounting evidence suggests that environmental and policy approaches aimed at increasing a population's physical activity levels are efficacious. For example, studies have shown that the physical and mental health benefits of moderate, unstructured physical activity are similar to those described for a more structured approach, such as aerobics or practicing sports [38, 39]. Lifestyle interventions, such as brisk walking, bicycling, and using stairs, can be easily integrated into our daily life and facilitate adherence to regular physical activity more than other forms of vigorous exercise [40]. Moreover, walking is the choice of most individuals who engage in regular physical activity [35, 37].

Regular routine physical activity may be the factor behind the low rates of obesity observed in certain countries (fig. 3). The Netherlands and Sweden have the highest rates of walking and bicycling, and obesity is less of a problem there than in more car-bound societies. Environments and policies that facilitate routine walking and bicycling offer a promising means of improving population levels of physical activity and overall health.

### Interventions to promote physical activity

A wide range of strategies and interventions have been used to promote physical activity in schools, worksites, health-care settings, and communities. Over the last decade, a growing body of research has accumulated that can be used to guide public health action. The US Preventive Services Task Force and the CDC are carrying out a systematic review of all of the English-language scientific literature on physical activity interventions. Fourteen categories of physical activity

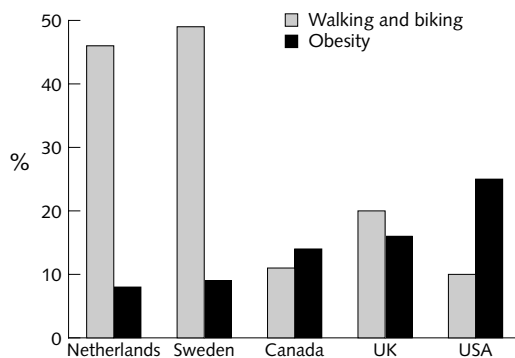


FIG. 3. Percentage of nonmotorized travel (walking and bicycling) and obesity rates in selected countries. Source: authors' elaboration based on data from the Victoria Transport Institute, 2002, and Obesity: preventing and managing the global epidemic. Report of a WHO consultation on obesity, 2000

interventions are being assessed. To date, analyses of 11 categories have been completed and the results have been published [41]. Six types of interventions are recommended:

- » Community-wide campaigns incorporating mass media and multiple other strategies
- » Point-of-decision prompts, such as signs recommending stair use
- » High-quality school physical education
- » Individually adapted health behavior change utilizing behavioral strategies such as goal setting, social support, reinforcement, and structured problem-solving
- » Social support in community contexts, for example, walking clubs
- » Creating or enhancing access to facilities or sites for physical activity, such as trails or worksite programs

Evaluations of transportation and urban planning related interventions are ongoing. The recommended interventions may be conceptualized as a menu of tested, proven, effective interventions that health departments, ministries, and local governments may draw from to create a combination of strategies and interventions that suits the local environment, culture, and circumstances.

In addition to effective intervention strategies, an important component of effective physical activity promotion programs is partnership development and communication. In the Americas, an excellent example of this type of information sharing and networking exists in the form of La Red de Actividad Física de las Américas/The Physical Activity Network of the Americas (RAFA/PANA). RAFA/PANA was created to build a “network of national networks” integrating members of public and private institutions, nationally and internationally, to promote health and quality of life through physical activity. RAFA/PANA works to develop, disseminate, and coordinate information and strategies for physical activity promotion in the Americas. The network includes about 75 members from over 20 countries representing public and private institutions that have physical activity promotion programs, as well as national and international organizations that can advise and sponsor member activities.

In the Americas, municipal and local governments can play an important role in fostering the public health agenda of physical activity promotion.

- » They are already working in physical activity and sports promotion. This contrasts with the still-limited health-promotion agenda in the public health sector.
- » They have decision-making power over the physical environment such as land use, transportation systems, and public safety, areas closely related to physical activity. They can also build related policies and influence legislative processes.
- » They can bring together different partners to build coalitions around the promotion of physical activity, including the private sector, the media, nongovern-

mental organizations, and the public sector.

- » In most cities there is an important demand from the public for action on issues related to public transportation, environmental health, green space, crime control, and facilities for physical activity.

Daily activities such as walking can have great impact on human health, and the physical environment can play a crucial role in encouraging them [5, 35, 37]. Many communities and local governments in the Americas are already engaged in creating healthful environments and devoting local resources to promote utilitarian nonmotorized transportation systems, as well as recreational physical activity in their communities, although not always inspired by physical activity promotion principles [36, 42]. In fact, pressing issues related to transportation, air quality, crime control, and zoning regulations are more often the impetus for community change.

### Components of a national physical activity policy

Developing a national, state, or regional policy for physical activity is a complex process. However, public policy for physical activity can be based upon good science and traditional public health approaches. A model framework is presented below. This model was developed as part of a joint WHO/CDC workshop on Physical Activity Policy Development that took place in Atlanta, Georgia, USA, from September 29 to October 2, 2002. The workshop was hosted by the CDC/WHO Collaborating Center for Physical Activity and Health Promotion, and the results are in press [43].

The comprehensive physical activity policy framework is a four-step process guided by an overall vision of sustainability, credibility, equity, and creativity. Although the steps follow in a logical sequence, countries may actually start the process at any point. Sound national physical activity policy will probably include all of the components of the framework.

#### Steps:

- » Make the case for physical inactivity as an important public health issue
- » Define the country-specific situation with respect to physical activity, noncommunicable diseases, determinants and barriers, and target populations
- » Identify both effective strategies and interventions and the settings that they may be applied in, as well as existing interventions and programs, actors, and resources
- » Implement interventions using a systematic approach characterized by 10 elements drawn from successful programs from around the world

Lastly, the comprehensive physical activity policy framework incorporates evaluation into each step along

the way. Evaluation may be simple or sophisticated and can include formative, process, and impact or outcome elements. Good evaluation is essential for developing, targeting, and maintaining an effective public health policy for physical activity. Figure 4 summarizes the framework described here.

## Examples of successful interventions in the Americas

### Community-wide campaigns

Community-wide campaigns involve the application of multiple types of interventions to different populations in multiple settings. For example, the Agita São Paulo program targets students in primary and secondary schools, older adults, and workers with a combination of special events, informational materials, mass media, school curricula, training for physical educators and physicians, worksite health-promotion programs, community exercise classes, and cooperative ventures with public agencies from several sectors (health,

education, transportation, and sports). Partnerships and public-private collaboration have been critical to the success of Agita São Paulo. Community-wide campaigns require integration and scope that usually depend upon the intense involvement of local city and community authorities in the design and execution of the interventions and programs. The mass media are an important part of community-wide campaigns, but mass-media interventions alone do not appear to be an effective way to promote physical activity. However, in conjunction with broad-based community programs, mass media can be very useful. [41]

#### Examples:

- » Agita São Paulo [44] (<http://www.agitasp.com.br>)
- » Muévete Bogotá ([www.idrd.gov.co](http://www.idrd.gov.co))
- » Healthy Municipalities ([http://www.paho.org/English/D/ops98-02\\_ch05.htm](http://www.paho.org/English/D/ops98-02_ch05.htm))
- » Vida Chile (<http://www.minsal.cl>)
- » Stanford 5 Cities Project [45]
- » Promoting Nutrition and Physical Activity through social marketing [46]

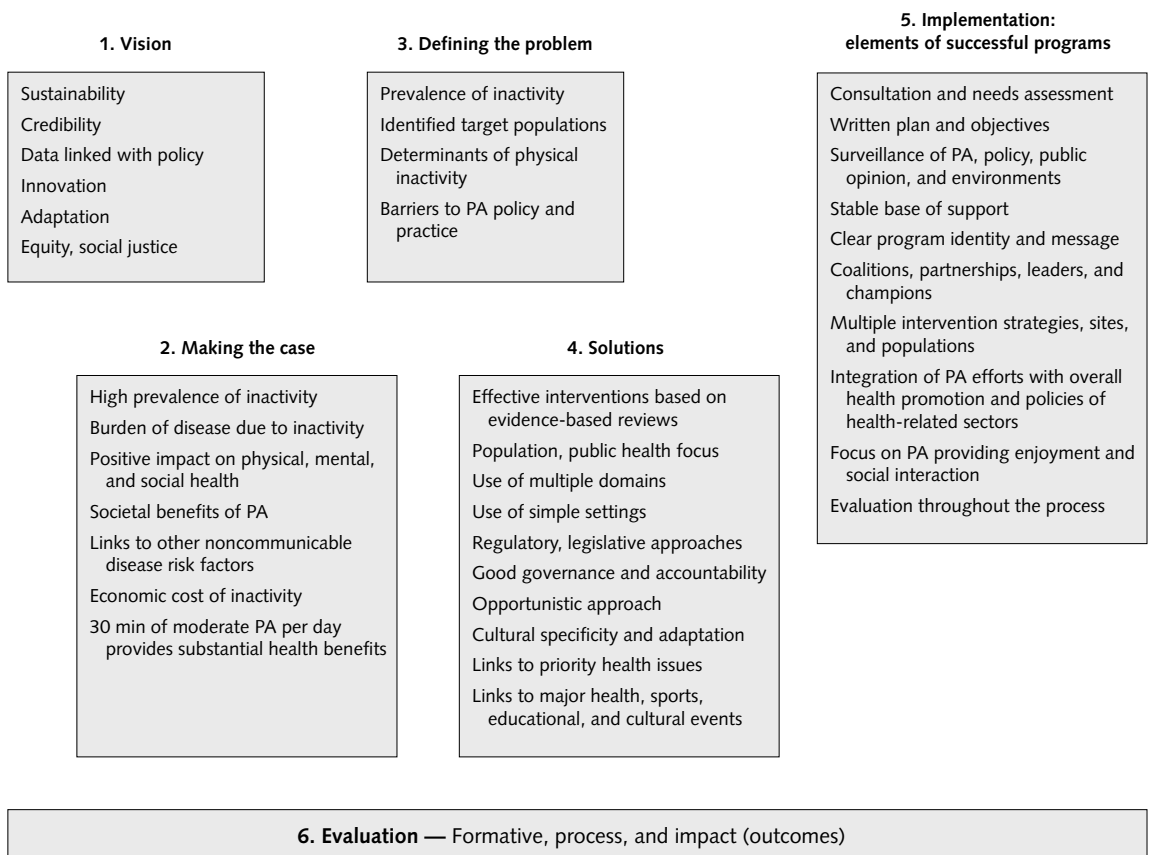


FIG. 4. Comprehensive physical activity (PA) policy framework

## Workplace interventions

The workplace is a very efficient means of reaching a majority of the adult population. A large body of research and practical experience exists on worksite health promotion. Worksite interventions include the promotion of stair use, on-site recreational facilities and programs, incentives for active commuting to work, and physical activity and nutrition counseling. Many of the recommended interventions from the US Preventive Services Task Force are worksite-based [41].

### Examples:

- » Kerr J, et al. Can posters prompt stair use in a work-site environment? [47]
- » Coleman KJ, Gonzalez EC. Promoting stair use in a US-Mexico border community [48]
- » CDC Stairwellness Project ([http://inside.nccd.cdc.gov/employee\\_handbook/serv\\_orgs/hns/about/activities.htm#stairwell](http://inside.nccd.cdc.gov/employee_handbook/serv_orgs/hns/about/activities.htm#stairwell))

## Physical education in schools

School physical education has great, but largely unrealized, potential for physical activity promotion. A large majority of children can be reached through physical education, but physical education programs are often of low quality and are increasingly being eliminated in order to reduce costs or increase focus on core academic subjects. High-quality physical education programs are an effective means of increasing physical activity among children and teaching skills, and they do not reduce academic performance [49]. A good physical education curriculum includes cognitive content as well as a variety of learning experiences in activities that range from basic movements skills to sports, dance, and gymnastics. Ideally, a good physical education program should be enjoyable and provide the basis for active living in the adult years. Effective physical education programs that are enjoyable, teach lifetime skills, increase levels of physical activity among children at school, and can be taught by a combination of physical education specialists and classroom teachers have been developed and implemented. [41]

### Examples:

- » The Coordinated School Health Program (CDC) ([http://www.cdc.gov/nccdphp/dash/about/school\\_health.htm](http://www.cdc.gov/nccdphp/dash/about/school_health.htm))
- » Take10 (ILSI) (<http://www.take10.net>)
- » SPARK Program. Sallis JF, et al. The effects of an innovative school physical education program with a focus on fun, skills, and lifetime physical activity (<http://www.sparkpe.org/index.jsp>) [49]

## Urban planning and community design

Pedestrian-oriented community design may improve health and quality of life by facilitating walking and cycling and increasing routine nonmotorized transportation and recreational physical activity. Although this is a new area of research, there is already good evidence that access to safe, attractive places to be active will increase participation in regular physical activity [35, 37]. There are also practical examples of urban planning and community design in Latin America that are leading to safer and more attractive environments for physical activity and may also stimulate social interaction and sense of community [36]. Indeed, in countries and cities where good alternative modes of public transportation systems exist and incentives for bicycling are in place, the situation is different than in cities where options for public transportation and bicycling are limited. In Bogotá, Colombia, introduction of an extensive network of bicycle lanes throughout the city has led to increased bicycle ridership in the last four years [50].

### Examples:

- » Montezuma R. La Transformación de Bogotá 1995–2000. Entre Redefinición Ciudadana y Especial. Ciudad Humana. 2002 [51]
- » Neiman AB, Jacoby ER. The First “Award to Active Cities Contest” in the Region of the Americas [36]

## Conclusions

Lifestyles and patterns of disease and health behavior have changed dramatically in the Americas over the past half-century. The Americas are highly urbanized; at least half of adults are physically inactive in most countries within the region; and 76% of mortality is due to noncommunicable diseases [6, 8]. Based on the evidence reviewed in this paper we can conclude that:

- » Physical inactivity is a critical public health problem in the Americas and contributes to the growing epidemic of obesity and noncommunicable diseases.
- » The majority of adults are insufficiently active to receive the health benefits associated with an active lifestyle.
- » Meeting the guideline of at least 30 minutes of physical activity a day is within the reach of almost all adults, and meeting this guideline provides substantial health benefits.
- » Although the exact amount of physical activity needed to prevent obesity is dependent upon energy consumption and energy expenditure, some individuals may require more than 30 minutes of moderate physical activity a day.
- » Effective population-based strategies exist for promoting physical activity in schools, worksites, and



communities, and good examples of their application are present in the Americas.

- » The successful promotion of physical activity rests on a broad spectrum of stakeholders and partners that are not necessarily linked to the health sector. Key sectors that may need to be involved are education, sports, transportation, local governments, environmental protection, public safety, and the private sector.
- » A logical policy and programmatic framework may be used to guide the development of national physical programs within public health and other sectors.
- » Promotion of physical activity will be enhanced by integrating and coordinating with broader health-promotion and noncommunicable disease-prevention programs.

Over the past decade, there has been a progressive consolidation of knowledge about physical activity and public health. By 1996, with the publication of the Surgeon General's Report on Physical Activity and Health, the extensive health benefits associated with physical activity were clearly established and widely accepted [5]. Similarly, our understanding of the behavioral determinants of physical activity has rapidly evolved [35]. Within the last three years, a large enough body of research has accumulated to develop evidence-based recommendations for community

interventions to increase physical activity [41]. The building blocks are in place to put together population-level programs to promote physical activity. The WHO Global Strategy for Diet, Physical Activity, and Health serves as a call to action to do so [52]. Although the rationale for promoting physical activity and the blueprint for doing so are clear, there is limited capacity in most countries within the Americas to actually develop, target, implement, and evaluate programs. This is true for noncommunicable disease prevention and health promotion in general, as well as physical activity specifically. Strengthening capacity and providing training for policy development, surveillance, evaluation, and partnership-building are essential for effective physical activity promotion and disease prevention. These major challenges confront public health practitioners around the globe. They are especially salient in the Americas, where the epidemiologic transition to predominance of chronic diseases is coupled with rapid urbanization. However, the Americas also have an abundance of creative community-based physical activity promotion programs, an effective network linking these programs, and strong national and regional interest in physical activity and health. The Americas are well positioned to take on the challenge of physical inactivity.

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# A public health framework for chronic disease prevention and control

Sylvia C. Robles

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## Abstract

*Chronic noncommunicable diseases are leading causes of death and disability in many developing countries. Several low-income countries lack mortality and morbidity data and do not yet know their burden of noncommunicable diseases. Cost studies are scarce, but in middle-income countries such as those of Latin America and the Caribbean, the cost of illness not only represents much of the direct costs of medical care, but also has an impact on family disposable income. Studies have reported that in low-resource settings, given incomplete health coverage and partial insurance, out-of-pocket expenses are high. Persons with chronic conditions, in many instances, have to forego care because of their inability to pay. Poverty and chronic noncommunicable diseases have a two-way interaction. These conditions warrant attention from poverty-reduction programs. Evidence shows that to have an impact on the burden of chronic diseases, action must occur at three levels: population-wide policies, community activities, and health services. The latter includes both preventive services and appropriate care for persons with chronic conditions. A public health approach embodies a systems perspective, containing the continuum of prevention and control, from determinants to care. In this framework it is critical to identify and address interactions and interventions that connect between and among the three levels of action.*

**Key words:** Americas, costs, noncommunicable diseases, prevention

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## Introduction

There is a pressing need in the international public health community to take action with regard to the epidemic of chronic noncommunicable diseases, given the burden on developing countries and among the poor. Traditionally, two contrasting approaches have been discussed. One is based mostly on health promotion, addressing the determinants of risk factors and disease. The other is based on clinical cost-effective interventions. A public health response must bridge these two approaches and integrate prevention and control of noncommunicable diseases in comprehensive programs. In this paper we discuss a first approximation to develop a conceptual framework to achieve integration of noncommunicable disease prevention and control, with particular reference to the situation of Latin America and the Caribbean.

## Social and economic burden of chronic diseases

There is wide recognition that chronic noncommunicable diseases are the leading cause of premature mortality and disability in the vast majority of countries of the Americas [1]. Among those under the age of 70, noncommunicable diseases account for 44.1% of deaths among males and 44.7% among females. The work force of most countries is affected by illnesses and risk factors that are highly preventable. The increasing relative importance of noncommunicable diseases in terms of disability-adjusted life years (DALYs) [2] is depicted in figure 1.

The importance of noncommunicable diseases is evident in persons of all ages and both sexes. Studies show that the prevalence of hypertension ranges from 14% to 40% among those 35 to 64 years of age, but nearly half are not aware of their condition, and on average, only 27% control their blood pressure [3]. Among the 9% to 18% of persons 35 to 64 years of age living with diabetes, nearly 60% already have at least

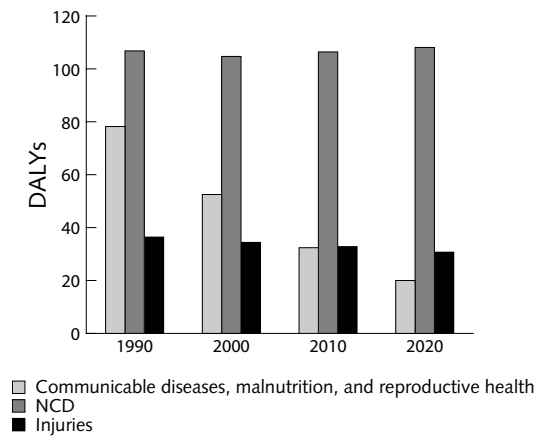


FIG. 1. Estimated trends in disability-adjusted life years (DALYs) according to cause in Latin America and the Caribbean, 1990–2020. NCD, Noncommunicable disease

one microvascular complication when diagnosed [4]. These complications, which can be prevented, lead to significant disabilities, such as blindness, amputation, and chronic renal failure. The number of persons with diabetes will increase almost twofold in Latin America and the Caribbean by the year 2020. It is estimated that nearly 80% of cases will be related to obesity. Women require special attention, because they have higher rates of obesity and physical inactivity than men [1]. It is not surprising that currently cardiovascular diseases are the leading cause of premature death among women in Latin America and the Caribbean.

No comprehensive study on the cost of noncommunicable diseases in Latin America and the Caribbean has been published. It is known that in the United States, the cost of cardiovascular diseases is on the order of 2% of the gross domestic product [5]. A study on the cost of illness in Canada found that 21% of all such costs are attributable to cardiovascular diseases, for a total of US\$12 billion annually [6]. These costs included treatment, consultations, and indirect costs, such as loss of income due to disability and death. Cardiovascular diseases were also considered responsible for the highest proportion (32%) of lost income due to premature death. The annual cost of diabetes in Latin America and the Caribbean has been estimated at US\$65.2 billion (2000) [7]. The different components used to estimate the total cost are presented in table 1. The highest costs are attributed to permanent disabilities due to complications from diabetes.

The cost and overall efficiency of interventions must be evaluated in terms of effectiveness and health gains for the population at large, but it is particularly important that consideration be given to those who bear the cost of such interventions, both the society and the individual patient. For example, antihypertensive treatment can cost up to \$100 per month, putting it

out of reach of persons from countries where the average monthly income may be only \$50 or less. A study in Jamaica reported that 57% of persons with cancer and diabetes became medically indigent because of the high proportion of the cost that required direct payment from patients; thus, 50% had to forego treatment because of inability to pay [8]. Health-services financing and policies impact on the possibilities that the population has to prevent and control chronic noncommunicable diseases, but the situation has yet to be appropriately documented in developing countries

Noncommunicable diseases have been erroneously regarded as diseases of affluence. This myth has led to misguided policy decisions [9]. Growing evidence demonstrating otherwise [10, 11] warrants attention from poverty-reduction programs. Although it has been widely demonstrated that persons with higher levels of physical activity and high consumption of fruits and vegetables have lower incidence rates of cardiovascular diseases and diabetes [12], it is very difficult for those living in a poor, unsafe neighborhood and working long hours to increase their physical activity and improve their diets. Neighborhoods and communities in the same country or city can have varying availabilities of food, access to health services, and opportunities to benefit from health-promotion initiatives.

Given the complexity that the burden of chronic noncommunicable diseases imposes on developing countries, the problem cannot be analyzed only in epidemiological terms. One-dimensional solutions, dealing with risk factors or diseases independently, have too narrow a scope. There are underlying common elements to several diseases and risk factors, as well as social dynamics and external influences. Public health agencies must adopt a comprehensive systems perspective that examines the multilevel processes that frame the prevention and control of noncommunicable diseases.

TABLE 1. Cost of diabetes in Latin America and the Caribbean, 2000

Type of cost	Amount (billions US\$)
Indirect	
Premature mortality	3,099
Permanent disability	50,633
Temporary disability	763
Direct	
Drugs	4,720
Hospitalizations	1,012
Consultations	2,508
Complications	2,480
<b>Total</b>	<b>65,215</b>

Source: ref. 7.

## Evidence for action

### Prevention

The incidences of disease and risk factors, as well as implementation of interventions, are affected by the societal context, which refers to the physical, social, and cultural environment (e.g., urban layout, safety factors, social support, social networks, cultural beliefs, language, gender roles, family composition, education, and income). The state and social groups play crucial roles in shaping the social context. Thus, prevention efforts need to extend beyond the individual to the environment that affects behavior. In order to improve understanding of how social dynamics influence health, several community-based trials of noncommunicable disease prevention were initiated in the United States and Finland in the 1970s and 1980s [13]. The results of these trials varied, probably because of various methodological considerations [14, 15]. In several studies, the control group accessed the intervention too soon after the study group to measure meaningful differences [16], either because of contamination or because of a policy decision to extend the program. Although some studies were inconclusive or the changes were difficult to interpret, the community organization process in conjunction with preventive health services seemed to be at the core of successful programs [17]. Some specific programs demonstrated reduction of risk factors and disease in closed population groups [18], such as interventions in the workplace consisting of a combination of regulations, health education, and individual interventions [19]. In view of the conflicting evidence, some have argued for a focus on health-services-based preventive interventions aimed at individuals [20, 21], such as smoking-cessation programs and nutrition counseling and screening. From an epidemiological point of view, it may be more feasible to demonstrate a statistical relationship for interventions aimed at individuals than to evaluate complex multilevel, multifactorial interventions. More recently, evaluation models that integrate behavioral and social science and consider multiple dimensions of interventions [22] are providing interesting results and another view to assess evidence.

Recent studies have attempted to determine what is required to achieve successful changes that both are effective and have the potential to reach all sectors of the population. The 2002 World Health Report [23] identified high blood pressure, overweight, and alcohol consumption to be the leading risk factors for mortality in Latin America and the Caribbean. Further analyses suggest that population-wide policies, such as legislation to reduce salt intake, combined with absolute risk reduction, are the most cost-effective interventions for the set of highly prevalent risk factors for cardiovascular disease in the region [24]. A previous review by

the Institute of Medicine of the United States points to community-based interventions in combination with preventive health services as the key strategy to reduce morbidity and mortality from noncommunicable diseases [25].

### Control of risk factors and disease

There is an important amount of research documenting the benefits and risks of various strategies for the control of risk factors and disease. The US Preventive Services Task Force [26] permanently reviews and grades the evidence for possible preventive interventions. In the area of chronic noncommunicable diseases, two strategies are noteworthy: screening, in particular for cancer of the cervix, breast, and colon as well as for hypertension; and counseling, for example, providing intensive behavioral dietary counseling for adults with hyperlipidemia and other known risk factors for cardiovascular disease. A third strategy for which there is increasing evidence is chemoprevention, such as the use of aspirin to prevent myocardial infarction and statins to control hyperlipidemias.

Therapeutic advances have been at the forefront in the improvement of disease management. Various researchers claim that the results of the WHOMONICA study on cardiovascular disease show that the reduction in cardiovascular disease mortality may be primarily due to the improvements in the treatment of disease rather than prevention [27, 28]. Others have challenged this interpretation on the bases of the large transformation power of population-based interventions at the policy level and the large variability in mortality and case-fatality rates among countries [29]. Most recently, a Finish study supported the latter, based on a significant decrease in mortality and a nonsignificant decrease in case fatalities [30].

The control of chronic noncommunicable diseases depends not on improving already available individual interventions, but in determining whether these interventions would be effective and sustainable under real-life conditions. Much of the evidence comes from efficacy trials conducted in well-controlled environments. Effectiveness or, more accurately, "population-based effectiveness" implies that the benefits of an intervention can reach all those who need it and that the system has the capacity to implement and sustain any given delivery program. The World Health Organization recently stated that the current acute health-care model has not proven effective in dealing with the prevention and control of chronic conditions [31]. Prevention and control of chronic noncommunicable diseases requires long-term contact with primary health-care services and good quality of care in order to be effective.

In general, it can be stated that strategies or favorable conditions at multiple levels are needed to trigger

overall system change. Three synergistic levels of action can be identified: policies and regulations addressing macro-level determinants, community-based actions that promote the participation of the population and affect demand, and health-service-centered modifications to address the needs of those with a given condition and offer preventive services.

### Policy-building

In industrialized countries, several adopted policies, laws, and regulations have been successful in preventing disease and injury, such as tobacco taxation and use of seat belts and helmets. The challenge, however, is in the process by which health policy is developed. Comparative analyses have demonstrated that these processes differ across social contexts and the nature of the proposed change, as well as preexisting political conditions [32]. Government action, either national or at the state and municipal levels, may require the support of internal or external technical and scientific establishments. In addition, the participation of the civil society is particularly influential for legislative changes that affect the interests of various stakeholders. Pivotal policy changes pertaining to noncommunicable disease prevention affect both public and private entities, often operating internationally. In this case, many small countries are unlikely to be successful by undertaking changes on their own [33]. Concerted international action and intercountry support are necessary to achieve outcomes.

### Community involvement

The decentralization of health services has focused primarily on the provision of care, transferring decision-making to the local level. In contrast, within the health sector, public health decisions have remained highly centralized in national, state, or provincial ministries of health, either because public health has not been part of reform efforts or because capacity has not been developed at the local level. At the same time, a process of government decentralization has taken place, giving more decision-making power to municipal governments. These local governments are increasingly addressing health issues beyond traditional basic sanitation activities, to include behavior change or “healthy lifestyles” within a larger social framework. Several of these activities need technical support, as investments without appropriate returns may occur. Thus, it is imperative to build local public health capacity and to bring to the table evidence of the public health impact of various strategies, by participating in the design, monitoring, and evaluation of these initiatives [34].

The integration of public health with local government initiatives calls for an active participation of the

population to which these initiatives are directed. Methodologies to learn and understand their views, perceptions, and needs, if incorporated into program design and evaluation, are likely to improve the possibility of successful outcomes.

### Shift toward responsive health services

Traditionally, interventions have been aimed at health-care delivery, at management, or at individual health professionals, such as physicians and nurses. To address chronic noncommunicable diseases, emphasis must be placed on demand, enabling patients to make informed decisions. It is the system behavior that makes the difference and not partial interventions. Based on this premise, a model for the care of chronic conditions aimed at improving outcomes includes five dimensions: clinical information systems, decision support, delivery system design, self-management support, and the use of community resources [35, 36]. Further evaluation is necessary to ensure the applicability of this strategy to developing countries, particularly in low-resource areas. The discussion of the development of a chronic care model clearly acknowledges that the policy and financial context must be conducive to change. In a study conducted by PAHO on Essential Public Health Functions, the area of quality assurance and population-based health services scored the lowest among 11 functions evaluated [37]. There is a lack of definition of standards and evaluation to improve quality, and incipient development of health technology assessment.

### Conclusions

A public health response to the prevention and control of chronic noncommunicable diseases requires the following:

- » The problem is addressed from a broad but cohesive systems perspective, based on epidemiologic evidence, and at the same time takes into account the social context and international environment;
- » Actions, whether to promote policy changes or to develop community-based programs or individual health service interventions, are evaluated in order to ascertain their population effectiveness;
- » Financing and a supportive infrastructure are present to assure sustainability and coverage;
- » The needs and perspectives of the population served are considered, so that they can be proactive participants in prevention and control programs.

These principles should guide the implementation of actions at the three levels identified: population-wide policy-making, community involvement, and health-services infrastructure. The three levels are interrelated but occur in different scenarios with different

stakeholders. It appears that approaches that bridge across levels necessarily include the involvement of the community and are generally more successful and efficient. Therefore, it is important that we understand the interactions across these various levels.

Figure 2 presents a graphic interpretation of this framework. The main challenge to the application of such a framework is the lack of institutional capacity in most developing countries. The organization of the public sector has been traditionally tailored to address communicable diseases and to provide direct patient care. There is a limited capacity for intersectoral action, but a large potential in decentralized govern-

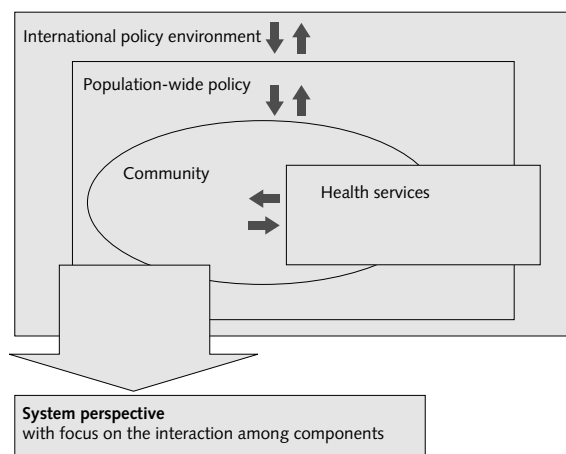


FIG. 2. Framework for a public health approach to the prevention of noncommunicable diseases

ments. The complexity of chronic diseases, their risk factors, and their determinants may require rethinking organizational models that can provide a public health response.

Figure 2 depicts the three levels of action: health services, community, and health policy, as well as the interaction among these levels.\* Population-wide policies have been separated from the international policy environment. The former can be national or subnational in scope, whereas the latter refers to transnational policies that can affect health, such as trade agreements and environmental protection. Application of this framework and the use of appropriate methods will contribute to elucidate the overall system dynamics in various settings.

\* Most research and interventions in public health occur within each of the different components of the system or levels of action: health services, community, and health policy. However, to understand the system as a whole, the points of interaction should be better understood, for example, the points of interaction for people with chronic conditions, which require a strong link between health services and the community, as well as outreach strategies for screening and counseling. Further development of the system would look at the mechanisms for the community to fully participate in policy-building processes and policy implementation. We have separated population-wide policy, which may be national or subnational in scope, from the international policy environment, which refers not only to health policy but more broadly to policies that affect health, such as trade and environmental protection. Methodologies for health impact assessment can make an important contribution to the understanding of these associations. Further development of this analytical framework and the application of appropriate methods will help clarify the overall system dynamics.

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# Food and agriculture policy: Issues related to prevention of noncommunicable diseases

Rachel Nugent

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## Abstract

*Good nutrition depends on access to a healthful food supply. Although a great deal of attention has been paid to food intake as a determinant of nutrition and overall health, little attention has been paid to the food supply system, health risks embedded in it, and its effect on people's choices. Most national governments intervene in their agricultural sectors in order to provide benefits to producers and consumers; however, these interventions are not designed with public health in mind. Governments should consider population nutrition and chronic disease risk when devising and implementing agricultural and food policies. They should seek opportunities to adjust agricultural and trade policies to be consistent with national health and nutritional priorities and guidelines. Although the paper gives several examples, country-specific policy changes can be determined only through analysis of individual country policies and nutrition conditions.*

**Key words:** Agriculture policy, food consumption, noncommunicable diseases, nutritious food supply

## Introduction

Nutritionists and public health experts have worked for years to inform the public about the relationship between the food we eat and our health. The topic of

food and health is a favorite of family magazines, health sections of newspapers, and even television doctors. Many governments, private associations, and consumer and producer organizations have issued advice and models to follow for healthy eating and drinking. Examples are the US Department of Agriculture dietary guidelines and food pyramid and the World Cancer Research Fund Guidelines. Through these efforts, a greater awareness and understanding of energy balance, micronutrients, nutrition-related diseases, and healthy diets has been achieved among the public, and new information is emerging all the time.

However, despite the sound professional advice of the experts and the voluminous information available to consumers about dietary health, trends in overweight and obesity prevalence across the Americas Region and worldwide worsen along with the incidence of diabetes, heart disease, stroke, and other nutrition-related non-communicable diseases [1]. Consumer knowledge of obesity issues and causes is not uniformly good across countries and populations in the Americas [2]. The problem is growing, and experts acknowledge that new solutions are needed [3, 4].

Although a great deal of attention has been paid to food intake as a determinant of nutrition and overall health, little attention has been paid to the food supply system, health risks embedded in it, and its effect on people's choices [5, 6]. Specifically, the vigorous discussions ongoing in the public health and nutrition communities over the global epidemic of overweight and obesity, particularly as risk factors for chronic diseases, have been focused on the end-users of the products and how to influence them, and have neglected the developers of the products and how to influence them. There is no doubt that understanding demand as a driving force of nutrition-related diseases is paramount in finding ways to reduce the problem, but an important piece of the puzzle is missing and should be inserted into the search for solutions. This piece is the food supply, and specifically: How can agricultural policies be directed toward making a healthful food supply available to a country's citizens?

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This paper argues for public health and agricultural policy experts to work together to find additional ways to improve the food choices available to people. It will highlight some aspects of agricultural policy that affect people's diets and, consequently, their risk of developing certain noncommunicable diseases. It will focus on a few agricultural and trade policies and how those policies could be adjusted to promote healthy diets. It will not draw conclusions about what is good or bad food, or good or bad agricultural and trade policy.

Many of the countries of the Americas are major agricultural exporters, but almost all are importers of food as well, so national governments are limited in their ability to control what is available to consumers. In addition, domestic farmers do not determine what appears on the grocery shelves. More than any other region in the world, consumers in the Americas purchase a high proportion of their food from stores and supermarkets rather than directly from producers. For Latin America this proportion is estimated at about 60%; in the Caribbean it averages about 30%; and in the United States it is about 80% [7]. Further, food distribution and marketing channels have become increasingly concentrated and provide a fairly common food-shopping experience to consumers across the region [8]. Still, even with these limitations, agroecological, geographic, and cultural conditions vary widely within the Americas, and a wide variety of dietary patterns is experienced. Policy can be used to alter those patterns in ways that reduce the risks of obesity and noncommunicable diseases but that are sensitive to regional differences.

## Holistic approaches to nutrition

Countries face multiple policy objectives within their agricultural sectors: to provide a decent livelihood for farmers, keep food prices low for consumers, raise revenue from export duties, earn foreign reserves in order to import other products, etc. Sometimes these objectives conflict with the goal of a healthful food supply and a healthy population. For instance, sugar producers may benefit from government subsidies for water and electricity, making sugar cheaper and increasing its use in manufactured products. Simultaneously, governments are seeking ways to reduce the sugar content in some manufactured foods. Such conflicts present opportunities for policy adjustments to improve the food supply.

The stakes are high. In addition to the clear connection between health and a high quality of life, there is increasing evidence that good health contributes to a growing economy [9, 10]. A healthy individual is more productive, is more educable, saves and invests more, and has a longer working life than a malnourished and

sick person [11]. In addition, healthy individuals miss work less often, incur lower medical expenses, rely less on others for support and assistance, spend less time engaged in health-seeking behavior, and create fewer health risks for others.

Aggregated to a national level, the economic impacts of poor health can be enormous. Obesity is estimated to cost the US economy \$117 billion annually in direct costs alone [12]. Economic analyses have not yet been done to estimate the costs of all nutrition-related diseases, but 6 of the top 10 risk factors for attributable disease burdens globally are related to nutrition or physical activity [13]. Measured only by lost years of productive life, these diseases together constitute a major hindrance to economic development.

Policies from the health, agricultural, and environmental sectors all affect nutrition directly, while other sectors (education, urban design, etc.) influence nutrition status indirectly [14–16]. Agricultural-sector policies have a large impact on a population's nutrition by determining what foods are produced in a country and by influencing agricultural imports and exports. Although agriculture ministries are sometimes deeply involved in the development of nutrition plans and guidelines, the primary activities of ministries relate more to maintaining production and income in the agricultural sector rather than a specific focus on the population's nutrition status.

A healthful food supply could be defined as one that provides accessible and affordable food choices that create the proper incentives for people to select a healthy diet. Along with consumer demand as influenced by culture, tradition, and tastes, many factors affect the accessibility and affordability of certain foods. Foremost are what a nation can produce from available resources and know-how and what it trades with other countries. In figure 1, the bidirectional relationship between food supply and demand shows that both producer and consumer choices are important determinants of diet. Diet is one factor in determining an individual's risk of developing a noncommunicable

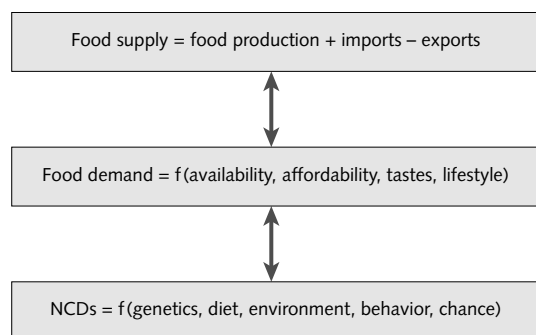


FIG. 1. Relationship between food supply and NCDs

disease, and it interacts with genetic and other factors [17]. The figure shows that attempting to reduce obesity and nutrition-related noncommunicable diseases while ignoring the influence of food supply reduces the options for dealing with the problem.

## Components of a healthful food supply

Much has been written about healthy diets and their role in preventing chronic diseases such as diabetes, cardiovascular disease, and hypertension [18, 19]. Although questions remain about the role of specific dietary risk factors, disease etiology, and other issues relating diet to noncommunicable diseases [20], some dietary recommendations can be made with confidence. Clear messages encourage consumers to choose a variety of foods, maintain low to moderate intakes of fats, sugars, salt, and alcohol, and get adequate nutrients and fiber, especially from fresh fruits and vegetables and whole grains [21].

The debates arise over the recommended sources and amounts of particular nutrients, especially those in animal products. They also arise over the nutritional needs of particular population groups and how to best deliver them. Finally, they arise over issues of behavior change and maintenance [20, 22]. This paper avoids those debates by addressing food supplies at a national level, recognizing that food intake on an individual basis can vary widely within a given country, and that not only genetic and environmental factors, but also the social, cultural, and economic conditions in each country, must ultimately determine the proper mix of food for its population. Thus, the production and consumption patterns and disease risks in each country and region should be carefully examined to identify opportunities for beneficial policy change. This paper attempts only to point in the direction of such analysis, which must be undertaken by a combination of nutrition and agricultural policy experts in each country, perhaps working with the United Nations Food and Agriculture Organization.

Policies that support a healthful food supply and potentially reduce the risk of noncommunicable diseases would therefore have the following characteristics:

- » Abundant fresh fruits and vegetables available for all income levels
- » Support of infrastructure for distribution of perishables to hard-to-reach populations
- » Choices of low-fat meat and dairy products
- » Reduction or elimination of subsidies for sugar, dairy, and meat products that promote consumption above levels that meet nutritional objectives
- » Support for smallholders producing for local markets at levels equal to or greater than those for large

producers

- » No export incentives on products in inadequate supply for the nutritional needs of domestic markets
- » Promotion of technology choices that result in more healthful processed foods, for example, less hydrogenation of oils
- » Support for research on appropriate biotechnology, including local varieties and plant protection, to serve domestic market nutrition needs

The above guidelines—and others could be added for specific health and agriculture conditions in countries—could be used as criteria in judging how well a country's agricultural policies are providing a food supply that reduces the risk of noncommunicable diseases. They will be illustrated by some examples of actual policies in the next section.

Two qualifications to the main point are important. First, reducing undernutrition is still of paramount importance in many developing countries. Dietary intake depends on what is available and affordable to people. There are many people (globally 842 million) who still do not obtain adequate quantities of nutritious food, largely because of poverty and conflict [23]. Some government programs aim to improve food security for these undernourished populations and play a critical role in antipoverty and development goals. These programs should be maintained but might be altered to achieve a better mix of foods for the beneficiaries (e.g., the US Department of Agriculture WIC program.)

Second, a factor limiting access to a healthy diet for all or part of a country's population is lack of food diversity. Although diversity has increased significantly in all regions of the world [24], climate and geography still present formidable obstacles to dietary choice, especially for those in rural areas. Most countries have large urban–rural differences in the availability of food, especially of fresh foods, and in the diversity of food supplies. Rural dwellers are more reliant on subsistence and locally produced foods, which may not provide a balanced diet. Food-distribution systems may be spotty because of inadequate infrastructure that limits refrigeration, slows transportation, and otherwise increases the costs of distribution to rural areas, thereby limiting food availability. Urban dwellers encounter far more choice of food varieties but still face obstacles of access (if they live in poor, underserved areas of cities or informal settlements) and affordability.

Some of these problems could be ameliorated by government policies, particularly those targeted to sustainable rural development and improvement of urban and periurban agriculture [25]. Nonetheless, most of the urban–rural differences in access to food cannot easily be resolved and are closely related to the still high rates of rural poverty, especially among those who depend on agriculture for their livelihoods.

## Trends in food consumption and trade

The past 20 years have shown a generally improving nutritional situation in the Americas, combined with a more trade-oriented and homogeneous food supply across the region [26]. The improvement is reflected in lower proportions and numbers of undernourished people. However, that public health problem is quickly giving way to greater risks of obesity and nutrition-related noncommunicable diseases in the region [27–29].

This section identifies recent trends determining the availability of the food commodities of most importance for noncommunicable disease risks in the Americas. These include livestock and dairy products, as well as oil and oil products, sugar and sugared products, fruits and vegetables, and the major inputs to production of those commodities. Most of the trends suggest increasing risks of overweight and nutrition-related noncommunicable diseases within the region.

As in other developing-country regions, consumption of livestock and dairy products has risen dramatically in Latin America and the Caribbean and will continue to outpace production growth [26]. Coarse grain production has increased by 20% in the past 10 years in Latin America and the Caribbean, and three-quarters of the increase is destined for animal feed use. Across the Americas, growth in grain production supports recent increases in chicken exports and continued growth in domestic chicken demand [30].

Oil and fat consumption since 1995 has risen at a fast pace in Latin America and Mexico and a slower pace in the United States and Canada due to saturation of those markets. In Latin America, the average per capita consumption of fats and oils (20 kg in some countries) is higher than that in other developing-country regions (11.3 kg overall) but is still lower than the developed-country average of 29 kg.\* Consumption of fish and fruits and vegetables has declined or grown very little in the past 20 years in much of the Americas Region, at least in part because of relative price increases for those foods [31, 32].\*\*

Government policies that alter relative food prices can have a powerful effect on consumers' choices of healthful foods. Studies support the connection between food prices and food choices, even in a high-income environment such as the United States [33]. The trend in prices of food commodities to consumers has not been in the right direction. US

data illustrate relative increases in the prices of fruits, vegetables, and fish and relative decreases in the prices of sugared products, oils and fats, and carbonated soft drinks between 1985 and 2000, as compared with the average of consumer prices over the same period [34]. The price of fresh fruits and vegetables jumped 188% between 1985 and 2000, the price of fish increased 77% in the same period, but fats and oils became only 35% more expensive and carbonated soft drinks only 20% more expensive. As would be expected, increases in the consumption of fats and oils and high-fructose corn syrup (in beverages) have easily outpaced increases in the consumption of fresh fruits and vegetables and fish [34].

The Americas Region is a net agricultural exporter, using earnings from exports to finance food and other imports. The United States and Canada are globally dominant cereal and livestock exporters. Agricultural trade surpluses are common throughout the region, notable exceptions being the Caribbean Subregion, which has been a net agricultural importer since the early 1990s, and Mexico [35].

The overall agricultural trade balance of the Latin America and the Caribbean Region has largely reflected that of its major net exporters, Argentina and Brazil, where large surpluses have tended to increase further during the past decade. Argentina and Brazil together account for about half of the region's total agricultural exports but less than one-quarter of its total imports. Cereals are the main imported commodity and are used largely to feed livestock. Dominant exports from the region are coffee, sugar products, bananas, and soy cake. Beef and veal exports have declined, despite the increases in cereals used as feed, reflecting a growing regional demand for livestock products. Raw sugar exports have declined as well, offset slightly by an increase in refined sugar exports, but also reflecting increased domestic sugar consumption [35].

In sum, the Americas are export-oriented in agriculture but also include many countries that are large importers of food. This is because many countries of the region export primary agricultural products and import niche and processed foods. Regional trends show increases in consumption of livestock and sugared products, and stagnant consumption of fish and of fruits and vegetables. These patterns are consistent with the comparative advantage and competitiveness of the farm sectors, but they may also contribute to less healthy eating patterns without commensurate benefits to other segments of society.

\* Consumption figures reported from FAO data are derived from food availability data rather than directly from household surveys of consumption.

\*\* Drewnowski A. Food price trends and relationship to obesity trends. Presented at Partnership for Healthy People Conference on Economics of Obesity, Washington, DC, April 14, 2003.

## Policies affecting the food supply in the Americas

Since the 1970s, both trade and domestic agricultural

policies in Latin America and the Caribbean have been strongly affected by market liberalization promoted by World Bank and International Monetary Fund structural adjustment, by NAFTA, and by World Trade Organization negotiations. But agricultural markets are still far from completely free, and nutritional needs may be one reason to avoid moving completely in that direction. Numerous types of agricultural and trade policies are acceptable under World Trade Organization rules, and developing countries have far lower rates of protection for their agricultural sectors than developed countries. This leaves room for certain policies that benefit nutritional needs while still complying with international trade agreements [36]. According to the US Department of Agriculture, "Because of the size and complexity of the US food system, an almost infinite combination of foods, production methods, end uses, and trade adjustments could work together to move diets toward recommended balance" [37]. This conclusion applies to all countries of the region except those most limited in production opportunities.

Numerous policies affect the types and volumes of agricultural production and trade that together determine what food is available to their populations. These range from subsidies to agricultural inputs to support for research and development of specific products to assistance to poor consumers for purchases of certain kinds of food. Most policies are intended to affect the price of a commodity to producers or consumers or both, or to affect a producer's income. This section mentions just a few examples of agricultural policies affecting food supply in countries of the Americas.

### Input policies

Governments frequently support their agricultural sectors by providing necessary inputs at low or no cost. Assuming a relatively competitive agricultural sector, these policies result in greater than normal quantities or lower than normal prices for the affected products. Inputs commonly subsidized are chemical fertilizers and pesticides and water, often through the provision of irrigation systems. The beneficiaries of these subsidized inputs tend to be large-scale farmers producing cereals and grains and fresh fruits and vegetables for export, rather than small producers of fruits and vegetables for local markets [36]. An example of this type of industry support was shown in the orange markets in Latin America between the early 1980s and the 1990s, particularly in Brazil and Mexico. Support was provided through subsidies for processing and storage infrastructure as well as credit availability that helped produce a higher-quality and stable supply of food for export [38]. This also may have had the effect of increasing the price of fruits and vegetables in the domestic market.

However, if domestically consumed fruits and veg-

etables were supported in this manner, those crops would become cheaper and more abundant and could improve nutrition. The most important policy measures are agronomic improvements, marketing assistance, scientific research in areas of pest control, agronomy, and post-harvest processing. All are needed for some of the healthful fruits and vegetables to be more price competitive and meet consumer demands [21, 30].

Agricultural-sector policy also affects the cost structure of the food-supply system through regulations of such matters as food safety, marketing rules and assistance, and financial and technical assistance, such as low-cost credit, infrastructure provision, and research and agricultural extension services. These approaches affect producers by increasing or lowering the costs of specific activities, thereby providing incentives or disincentives for certain kinds of production.

Subsidies for irrigation systems and fertilizers result in lower prices of cereals and grains, thus benefiting livestock producers, manufacturers of packaged foods, and other heavy users of water and chemical inputs, such as sugar producers. In the United States, sugar producers are supported by a combination of import limitations, price support, and irrigation subsidies. These input incentives can have a dramatic effect on farmers' choices about production, and thus what is available and affordable to consumers. According to the US Department of Agriculture, "Production is highly concentrated... [With a reduced demand for sugar] producers in these regions would likely shift production to fruits and vegetables or field crops" [37].

### Production policies

Direct price support for production of certain commodities or income support to certain farmers is also used to increase output. For instance, beef production in some African countries and in China is rising at a faster rate in recent years due to direct support policies. Because of the insufficiency of protein and fat in the diets of most Africans, this could be considered a nutrition-positive policy, especially if the support is geared toward making meat more affordable to consumers. On the other hand, increases in beef output in the United States and Canada are headed for the export market, including growing quantities to Mexico and the Caribbean [31]. The increased intake of animal protein and fat exceeds the nutritional needs of all but the region's poorest consumers.

Dairy production has grown substantially in the Latin America and the Caribbean Region over the past decade (34%), fueled by increased demand from both domestic and international markets [30]. Limits on subsidized US production have kept milk production stable in the United States, but consumer preferences have shifted from milk to higher-fat products such as

cheese. Current policies subsidize US exports of certain dairy products, including cheese and butterfat [31]. As with beef, nutritional benefits only occur in the dairy-importing countries if the products are purchased by consumers who do not already have diets excessive in animal fat.

### Trade

Trade in food and agricultural products has increased steadily over the past 20 years, and the countries of Latin America and the Caribbean trade more agricultural commodities on a per capita basis than any other developing region [35]. As a result, they are heavily dependent on export earnings from agricultural trade for macroeconomic purposes. Thus, the macroeconomic goals of engaging in agricultural trade can easily override other goals. These objectives may or may not be consistent with nutritional needs. Exporting products that are needed to meet domestic nutritional needs increases the prices of those products and reduces the amounts available to domestic populations.

An example of macroeconomic priorities driving a country's agricultural choices is shown in Chile's emergence in the 1970s as one of the world's leading exporters of off-season temperate fruits. A good climate and public-sector investment in centralized processing infrastructure combined to position Chile as a highly efficient producer of fruit at a time when global demand was rising. Production policies favoring large plantation agriculture supported the sector's development as a means of earning foreign exchange rather than providing more fruit for domestic consumption. Between the mid-1970s and the mid-1990s, almost all of the increased fruit production was exported, as domestic utilization remained flat [38]. Whether this policy was detrimental to the nutritional needs of Chile's population depends, of course, on whether the export drive reduced the adequacy of domestic consumption of fruit.

Trade policies are often used to refine the agricultural mix available within a country for a variety of purposes, including meeting consumer demands and earning revenue. From a nutritional point of view, the desired outcome is increased consumption of "healthier" foods and decreased consumption of "less healthy" foods, relative to some measure of adequacy of both. However, governments sometimes apply such policies to less healthful foods either to meet consumer demand or to support an existing production sector. This approach is used in a number of countries to ensure adequate supplies of oils in the face of rising demand. The wide variation in fat that occurs in different types of oil opens the door to policies that might encourage more "healthful" oils. For example, coconut oil is 86% fat, while flaxseed oil is 4% fat [32].

World production of oils and fats continues to

increase, with developing countries accounting for a growing share of the output (64% in 2000.) These increases are a result of increases in demand and market liberalization, as well as policies to increase investment in oil production through technical and financial support to the sector. The greatest increases globally are in palm and palm kernel oil, which are very high in saturated fats. Production in the Americas is concentrated in vegetable oils, which pose a lower health risk. Production of oil crops in Argentina and Brazil grew by 30% in the past 10 years [30].

Some of the oil-importing countries of the Latin America and the Caribbean Region have removed import tariffs or reduced nontariff barriers in order to respond to growing demand and reduce price increases. Oil exporters in the Americas (United States, Canada, Brazil, and Argentina) have also increased production and exports, in some cases by providing incentives for export [26].

### Programmatic and policy solutions

These are but a few of the examples of the specific policies that determine what food appears in markets of the Americas. As countries work to achieve a holistic approach to long-term population health, consideration of specific deficiencies in their food systems that can be corrected through modifications in agricultural and trade policies is an important endeavor. Such deficiencies might be related to overall supply problems for certain foods, to distribution issues that prevent access for some portions of their population, or to farm-level choices about the production process that affect the healthiness of foods. There will be multiple options for addressing these deficiencies, and the best policies from an efficiency perspective are those that minimize distortions of resource allocations and dislocation of existing production and trade systems. However, ultimately policies should be measured against the multiple objectives of all sectors of society, with priority placed on providing a sufficient, safe, nutritious, sustainable, and equitable food supply [39].

Other useful actions are for dietary guidelines to take into account cultural, social, agroecological, and economic realities; gathering of additional food-supply and food-composition information, especially where it is lacking in developing countries; and alternative ways to improve food supplies, such as fresh food grown in urban and periurban areas.

Development of food-based nutrition policies is one of many ways in which governments and communities may address growing obesity- and nutrition-related noncommunicable disease problems. However, this approach can only go so far toward encouraging more healthful agricultural supply for a country's population. The following factors limit the scope of agricultural policies to effect nutritional change:

- » It is difficult to target the needs of specific populations, especially in countries with a dual malnutrition situation where undernutrition and overnutrition coexist
- » World Trade Organization rules generally prohibit restrictions on the trade of food products except in public health emergencies
- » Many food products are closely related substitutes and complements in production and consumption, and restrictions on one will lead to changes in the production and consumption of others
- » The public and policy makers have time horizons that discount the long wait before the onset of chronic diseases

Agricultural policy is difficult to change because of the political and economic importance of the sector in most countries [40]. Global trade talks begun in 2000 to address agriculture have been arduous and unpromising [41]. Assuredly, serious change in existing policy regimes will take a long time. Difficulties arise because the beneficiaries of existing policies

fight change and are often in a position to influence political decisions. Those who would benefit from a change toward a healthier food system—current and future consumers—may be less aware of the existence and effects of policies that affect their health than are the producers that benefit from them, especially when the health impacts are likely to occur in the future. Finally, there are real costs to changing policies in the agricultural and trade sectors. These include the costs of altering production processes, supply sources, and formulas, as well as potential loss of export earnings. These costs must be weighed against the uncertain and future benefits of changing existing policies—a difficult tradeoff. Nonetheless, unhealthy diets do impose substantial real costs in the form of ill health and an overburdened health sector. Successful advocacy for change will involve finding the win-win possibilities for change and precisely identifying the benefits of change, including the avoided costs of increased nutrition-related noncommunicable diseases.

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# Book reviews

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**Annual Review of Nutrition. Volume 23.** Edited by Donald B. McCormack; associate editors, Dennis M. Bier and Robert J. Cousins. Annual Reviews, Palo Alto, Calif., USA, 2003. (ISBN 0-8243-2823-X; ISSN 0199-9885) 443 pages, hardcover. US\$160.

This is the 23rd volume of *Annual Reviews of Nutrition*. Like its predecessors, it consists of carefully selected reviewers and their reviews of areas of current controversy or significant advances. This one presents 18 chapters on a wide variety of topics. Those concerning selenoprotein synthesis, iron status and neural function, vitamin D and its analogues, dietary iron absorption, reducing food-borne illness, and endocrine control of body weight and bone mass will be of particular value to nutrition and food scientists working in developing countries. Readers may wish to refer to previous volumes for topics of equal interest and value. The *Food and Nutrition Bulletin* will make annual note of the publication and contents of this useful volume.

**Antioxidant vitamins and health: Cardiovascular disease, cancer, cataracts, and aging.** Claude Fernand Bourgeois. HNB Publishing, New York, 2003. (ISBN 0-9664286-6-8) 310 pages, hardcover. US\$72.

Ten chapters of this book review studies published in the international scientific literature on the role of antioxidant nutrients in chronic degenerative diseases and conditions, including cardiovascular disease, cancer, cataracts, and aging. It begins with a discussion of free radicals and the reactive oxygen species generated in vivo and goes on to describe the mechanism of antioxidation and antioxidant defense in humans. It reviews and discusses epidemiological studies carried out over the past two decades associating antioxidant vitamins and cardiovascular disease, cancer, cataracts, and aging. A final chapter presents conclusions on each of these topics. These conclusions are evidence-based and carefully guarded. Three appendices give recommended dietary allowances of antioxidation vitamins,

the structure and properties of antioxidant vitamins and lipid peroxidation, and the autoxidation chain reaction. The 1,093 references are compiled in a final chapter.

**Halal food production.** Mian N. Riaz and Muhammad M. Chaudry. CRC Press, Boca Raton, Fla., USA, 2003. (ISBN 1-58716-029-3) 379 pages, hardcover. US\$149.95.

Halal foods are those permitted or lawful for Muslims. The book is not written to guide or inform the Muslim consumer but to provide the information that the food industry needs to produce food products that meet their needs at both the national and the international levels. It provides information about Halal food laws and regulations, general guidelines for Halal food production, trade, and import requirements in different countries. It also covers specific Halal production requirements for meat, poultry, dairy products, fish, seafood, cereal, and confectionery and the role of gelatin, enzymes, alcohol, and food supplements. Guidelines for labeling, packaging, and coatings are also presented.

This book distinguishes among Halal, kosher, and vegetarian food production. Procedures are included to help food companies obtain Halal certifications. Considered also are biotechnology and genetically modified organisms within the context of Halal regulations. Its chapters provide specific and practical guidelines in the first 183 pages. These are followed by an equal number of pages devoted to 14 appendices that give relevant excerpts from the Food and Agriculture Organization/World Health Organization Codex Alimentarius, Halal industrial production standards, export requirements for various countries, recommended ritual slaughter guidelines, and acceptable ingredients. They describe related food laws for Malaysia and Singapore as well as the US states of New Jersey, Illinois, Minnesota, California, and Michigan.

In view of the growing markets for Halal foods

worldwide in both Western and Islamic countries, this information on food service, branded packaged foods, direct-marketed products, and food ingredients is timely. Nutrition and food scientists in both academia

and industry need the convenient access to it provided by this book.

—*Nevin S. Scrimshaw*

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## Micronutrient activities and research report

For more information on this report, contact Wilma B. Freire (freirewi@paho.org), Unit Chief, Nutrition Unit, or Sunny S. Kim (kimsunny@paho.org), Technical Officer, Nutrition Unit, at the Pan American Health Organization/World Health Organization (PAHO/WHO), Nutrition Unit, FCH/NU, Pan American Health Organization, 525 23rd St., NW, Washington, DC 20037, USA.

### 1. Activities related to iron, folic acid, and zinc

#### 1.1. Guidelines on iron compounds for food fortification

In the Americas, wheat and/or corn flour are commonly consumed staples and excellent vehicles for fortification with iron, folic acid, other B vitamins, and nutrients. About 22 countries are already fortifying wheat and/or corn flour with at least iron and other micronutrients. Still, there is much room for optimizing these fortified foods and reinforcing the programs, and the growing scientific evidence and lessons learned from country experiences are providing the know-how to achieve this. Despite the ongoing fortification of flour with iron, little contribution has been made to the reduction of iron-deficiency anemia in the population, and variations in terms of enforcement of regulations, types and levels of the fortificant, manufacturing techniques and standards, and quality control and assurance, as well as other components of the program, have been identified. One essential component of the process that needs to be addressed involves the type and amount of iron compounds used in food fortification. Factors to be considered in the selection of iron compounds, in terms of bioavailability, organoleptic characteristics, technological compatibility, and costs, need to be specified. Criteria to define the levels for iron fortification and discussion of the feasibility of change to current fortification programs also need to be addressed. To this end, a technical consultation sponsored by the Pan American Health Organization (PAHO), the International Life Sciences Institute (ILSI), the US Agency for

International Development (USAID), and the International Vitamin A Consultative Group (IVACG) was held in 2001, in order to develop practical guidelines for the countries of the Americas on the type and level of iron compounds for food fortification based on state-of-the-art information (Nutr Rev 2002 Jul; 60(7 Pt 2):S50–61; PAHO/ILSI/USAID/IVACG, 2002).

#### 1.2. Guidelines on recommended levels of folic acid and vitamin B<sub>12</sub> fortification

The evidence linking folate insufficiency with the occurrence of neural tube defects and the protective effect of increased folic acid intake in the prevention of neural tube defects have lent support to the recommendation of the US Institute of Medicine in the National Academy of Sciences that all women of childbearing age should consume 0.4 mg (400 µg) of folic acid daily. However, achieving this recommended level through consumption of naturally occurring folates in foods is very difficult because of their low bioavailability. Providing folic acid supplementation to the entire at-risk population is also a major logistical challenge, even in developed countries. For these reasons, fortification of food with folic acid is important for reaching a large number of the target population to increase their folate levels.

At present, of the 22 countries in the Americas that are currently fortifying wheat flour with iron, 17 are also adding folic acid at levels that vary between 1.5 and 3.4 mg per kilogram of flour. Food fortification with folic acid has been considered as a favorable intervention because of the technological compatibility in adding folic acid to the premix for food fortification; folic acid has not been shown to cause sensory changes in the final products, and the cost of adding folic acid to foods does not significantly increase the cost of the final products. Nevertheless, folic acid fortification should be promoted in countries that are currently not fortifying with folic acid, and the current level(s) of fortification should be reviewed, taking into consideration the nutritional requirement, the consumption level of the food vehicle, cost, and safety.

In addition to folate, vitamin B<sub>12</sub> has received much attention for its association with pernicious anemia and blood levels of homocysteine, which is a risk factor for heart disease and stroke when elevated. Vitamin B<sub>12</sub> deficiency can occur in individuals with dietary patterns that exclude animal or fortified foods and in adults 50 years of age and older who are unable to absorb vitamin B<sub>12</sub> in food. Given that the diet in Latin America and the Caribbean is generally based on corn, rice, wheat, beans, and potatoes, with relatively low intakes of foods of animal origin, vitamin B<sub>12</sub> deficiency is a major concern. Furthermore, there are concerns about the delay in the diagnosis of hematological and neurological impairments from vitamin B<sub>12</sub> deficiency and possible acceleration of neurological manifestations of vitamin B<sub>12</sub> deficiency in the presence of high levels of folate. Thus, vitamin B<sub>12</sub> should also be considered when fortifying with folic acid. In light of these considerations, PAHO, the March of Dimes Birth Defects Foundation (MOD), and the Centers for Disease Control and Prevention (CDC) organized a technical consultation in January 2003, on "Recommended levels of folic acid and vitamin B<sub>12</sub> fortification" (Nutr Rev 2004, in press).

### **1.3. Reviewing regional progress on flour fortification with iron, folic acid, and vitamin B<sub>12</sub>**

With the results of the previous two activities, a regional meeting was held as the next step in the process of translating current scientific and programmatic knowledge into practice, transferring the knowledge on optimizing flour fortification into the hands of policy makers and program implementers in the Americas. In October 2003, PAHO jointly sponsored a regional meeting in Santiago, Chile, with CDC, MOD, and UNICEF, hosted by the Institute of Nutrition and Food Technology, University of Chile (INTA). The meeting was specifically held in Chile, where local counterparts shared the impressive results of a recent impact evaluation of the national wheat flour fortification program with folic acid, through the support of PAHO, CDC, MOD, INTA, and the Chilean Ministry of Health (J Nutr 2003; 133(10):3166–9). Representatives of the Ministry of Health, regulatory entities, and the flour industry from 20 countries throughout the Americas actively participated in the meeting. The objectives of the two-day regional meeting were to:

- » Review the nutritional status in terms of iron, folate, and vitamin B<sub>12</sub> deficiencies in the Americas and the situation of flour fortification with iron, folic acid, and vitamin B<sub>12</sub>;
- » Review and discuss the experiences and lessons learned from national wheat flour fortification programs;
- » Review the conclusions and recommendations of the technical consultations on "Iron compounds for

food fortification" (PAHO/ILSI/USAID/INACG) and "Recommended levels of folic acid and vitamin B<sub>12</sub> fortification" (PAHO/MOD/CDC);

- » Discuss and identify programmatic solutions to optimize flour fortification in the Americas.

### **1.4. Advancing the regional agenda country-by-country**

Based on the results of the regional meeting, PAHO is currently developing a country-specific agenda to strengthen national food-fortification programs. PAHO will provide direct technical cooperation to countries to strengthen ongoing micronutrient programs in the areas of:

- » National plans of action
- » Legislation
- » Regulatory monitoring and quality control
- » Household monitoring and surveillance
- » Training and education
- » Communication and social marketing

### **1.5. Regional initiatives and country proposals**

Continuous effort at the regional level to bring food fortification and improvement of the micronutrient situation into the forefront of national agendas will be maintained through the intercountry exchange of experiences and ideas, strategic partnerships with the food industry through the Latin American Association of Industrial Millers (ALIM), alliances with other sectors (economic and finance, agriculture, education, sustainable development, etc.), and communication and advocacy among these various partners. Specific subregional activities to maximize limited resources and advance clusters of countries will also be implemented through careful planning and evaluation of existing resources and needs. Country-specific projects to strengthen national food-fortification programs will be developed and implemented. In 2003, PAHO provided direct technical assistance to Bolivia and the Dominican Republic to strengthen their national fortification alliance and elaborate project proposals requesting assistance from the Global Alliance for Improved Nutrition (GAIN). The Ministries of Health of these two countries and the Office of the First Lady of Bolivia, with the support of PAHO and other partner agencies including UNICEF, USAID, and the World Food Program (WFP), reinvigorated their national micronutrient committees and mobilized various ministries, local industries, consumer associations, universities, institutes, media, other civil societies, and nongovernmental organizations to partner together in coordinating and monitoring food and nutrition programs, including food fortification. In the Central American countries, a subregional micronutrient committee was developed with the support of the Institute for Nutrition of Central America and Panama (INCAP)/PAHO, UNICEF, and the Micronutrient Initiative, and a collective regional

project proposal was prepared and submitted to GAIN. Follow-up to these activities and in other countries will be conducted.

## 2. Experiences or lessons learned

See 1 and 6.

## 3. Partners or organizations

Partners in the aforementioned activities include the Ministries of Health of respective countries, local flour industries, ALIM, and other private enterprises, including DSM Nutritional Products, BASE, Fortitech South America, Granotec Chile, and Instituto Teletón Chile. Partner organizations and agencies include UNICEF, MOST/USAID, ILSI, INACG, MOD, CDC, INTA-Chile, WFP, and GAIN, among others.

## 4. Plans and goals

PAHO is assisting countries to strengthen their national food-fortification programs and consolidate subregional efforts in order to improve the nutritional situation of the populations and contribute to the Millennium Development Goals of reducing child mortality and improving maternal health in the region.

## 5. Assistance needed

In the area of technical cooperation, PAHO will call upon the support of experts and leading agencies and organizations in specific areas of expertise. Financial support for both the regional initiatives and country-based activities is continually being sought.

## 6. List of visual or other materials (in the order of mention above)

- » Iron compounds for food fortification: guidelines for Latin America and the Caribbean 2002. English; Nutr Rev 2002 Jul; 60(7 Pt 2):S50-61; also available at [www.paho.org](http://www.paho.org).
- » Compuestos de hierro para la fortificación de alimentos: guías para América Latina y el Caribe. Spanish; PAHO/ILSI/USAID/INACG, 2002; also available at [www.paho.org](http://www.paho.org).
- » Recommended levels of folic acid and vitamin B<sub>12</sub> Fortification: Conclusions. In press, Nutr Rev 2004.
- » Consumption of folic acid-fortified bread improves folate status in women of reproductive age in Chile. J Nutr 2003 Oct; 133(10):3166-9.
- » Chile Regional Meeting Report. In progress; PAHO/CDC/MOD/INTA, 2004; background information and presentations available at [www.paho.org](http://www.paho.org).

## FAO and IUFOST join forces to establish a global database of food science and technology research projects addressing worldwide food needs

Researchers involved in food science and technology research projects relevant to worldwide food needs, especially those of developing countries, will be invited to contribute brief key details of their projects to a new searchable database developed and operated jointly by the United Nations Food and Agriculture Organization (FAO) and the International Union of Food Science and Technology (IUFOST).

The purposes of this database are to collate information about relevant food research projects, to facilitate information-sharing among food scientists globally, and to provide a resource and contact base especially for developing countries. Access will be at [www.fao.org/INPhO](http://www.fao.org/INPhO).

The initiator of the database project, Professor J. Ralph Blanchfield, stated:

This collaboration between the two main international bodies, FAO and IUFOST, deserves the support of all food scientists and technologists worldwide. IUFOST is asking all its national adhering bodies to request and encourage their members involved in research projects in food science and technology, wherever carried out and applicable to improving food quality and availability, especially for developing countries, to contribute details of their projects to the database. We shall also be asking research institutions to facilitate entries by their staff and aid agencies to contribute details of projects that they support.

For the first time, there will be organized worldwide knowledge of what scientists and technologists have been or are doing in relation to this crucially important subject, where the work is being done, and for which developing countries. The IUFOST Task Force will monitor inputs and conduct searches and will be able to:

- » See where the gaps are and draw attention to them;
- » Put individuals who are unknowingly working on similar projects for different developing countries in touch with each other;
- » Possibly "broker" the application of projects that have been or are being successful to other developing countries where they could also be relevant.

FAO is the main international agency concerned with addressing the serious problems of food insecurity in the world. IUFOST is the United Nations-type international body in which member countries are represented by their national food science and technology societies (termed "adhering bodies"). It has been seeking new ways to give practical effect to the food-security principles embodied in its Budapest Declaration of 1995.



Out of this was born the database concept.

At a practical level, the scheme and database requirements were developed by an IUFOST Task Force led by Professor Blanchfield, and the database was constructed and implemented by the FAO Agriculture and Food Engineering Technologies Service as a module of its INPhO mega-database. For more information, contact J. Meech at [iufost@ca.inter.net](mailto:iufost@ca.inter.net). The IUFOST website is [www.iufost.org](http://www.iufost.org).

**November 15–17, 2004. XXII International Vitamin A Consultative Group (IVACG) Meeting: Vitamin A and the Common Agenda for Micronutrients. Lima, Peru**

*For information contact:* IVACG Secretariat. Tel: 202-659-9024; Fax: 202-659-3617; e-mail: [hni@ilsilsi.org](mailto:hni@ilsilsi.org); Web: <http://ivacg.ilsilsi.org>

**November 18, 2004. 2004 International Nutritional Anemia Consultative Group (INACG) Symposium. Lima, Peru**

*For information contact:* INACG Secretariat. Tel: 202-659-9024; Fax: 202-659-3617; e-mail: [hni@ilsilsi.org](mailto:hni@ilsilsi.org); Web: <http://inacg.ilsilsi.org>.

**November 19, 2004. International Zinc Nutrition Consultative Group (IZiNCG) Symposium: Moving Zinc into the Micronutrient Program Agenda. Lima, Peru**

*For information contact:* IZiNCG Secretariat. Tel: 530-752-1992; Fax: 530-752-3406; e-mail: [izincg@insp.mx](mailto:izincg@insp.mx); Web: <http://izincg.ucdavis.edu>

# Correction to Vol. 25, No. 1 (Supplement 2): International Zinc Nutrition Consultative Group (IZiNCG) Technical Document #1

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The description of the Micronutrient Initiative that appeared in the Acknowledgment section of the IZiNCG supplement (p. S95) should read as follows:

The Micronutrient Initiative (MI) is a not-for-profit organization specializing in addressing vitamin and mineral deficiencies. MI is governed by an international Board of Directors. MI supports and promotes food fortification and supplementation programs in Asia,

Africa, and Latin America and provides technical and operational support in those countries where vitamin and mineral deficiencies are most prevalent. MI carries out its work in partnership with other international agencies, governments, and industry. MI is based in Ottawa, Canada, and maintains regional offices in New Delhi, India, and Johannesburg, South Africa.

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—*corporate author:*

2. Committee on Enzymes of the Scandinavian Society for Clinical Chemistry and Clinical Physiology. Recommended method for the determination of gamma-glutamyltransferase in blood. *Scand J Clin Lab Invest* 1976;36:119–25.

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3. Brozek J. Malnutrition and human behavior: experimental, clinical and community studies. New York: Van Nostrand Reinhold, 1985.

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4. American Medical Association, Department of Drugs. AMA drug evaluations, 3rd ed. Littleton, Mass, USA: Publishing Sciences Group, 1977.

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