2

The Role of Chemistry in Addressing Hunger and Food Security

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2.1

Chemistry is the Backbone of Food and Nutrition

Chemistry has provided the backbone in understanding the structure, organization and functions of living matter. Biochemistry, in particular, is composed of the structural chemistry of living matter, the metabolism or chemical reactions of those living matters, and the molecular genetics of heredity. The ability of plants to derive energy from sunlight and animals and humans to derive energy from food begins with chemistry and the principles of thermodynamics, and the basics of food itself are made of chemical and biological structures – amino acids, sugars, lipids, nucleotides, vitamins, minerals and hormones.

The chemical elements are key to understanding our modern day food and nutritional needs. In the late 18th century, many of the chemical elements had been defined, including nitrogen from ammonia, followed by the discovery of protein in egg albumin, inorganic elements and amino acids. The characterization of energy and calorimetry were also critical for the food and nutrition science world and could not have been understood without the use of physiological chemistry [1]. By studying persons engaged in labor and exercise and the amount of heat released, and understanding metabolics, the kilocalorie was defined – the energy needed to raise the temperature of 1 kg of water by 1 degree Celsius.

Starting in the 1800s, scientists worked backwards by characterizing disease states and, from defined foods, they discovered what was lacking or deficient, honing in on specific vitamins and minerals. For example, in the 1880s, deficiency of thiamin through fractionation of rice polishing was discovered to cause beriberi. In 1870, vitamin C deficiency was discovered to be the root cause of scurvy [1]. In the mid 1700s, British naval commander James Lind pleaded with the British Navy to make citrus foods available on all sea voyages. In a book he authored after an especially long journey with high mortality among the crew, he described miracle cures achieved with the use of lemon juice. Almost 60 years later, the British Navy did provide citrus foods when Captain Cook succeeded in avoiding scurvy altogether by giving his sailors lime juice on three successive voyages

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Table 2.1 The known 51 essential nutrients for sustaining human life (adapted from [3]).

Air, water and energy	Protein (amino acids)	Lipids-fat (fatty acids)	Macrominerals	Trace minerals	Vitamins
Oxygen	Histidine	Linoleic acid	Na	Fe	A
Water	Isoleucine	Linolenic acid	K	Zn	D
Carbohydrates	Leucine		Ca	Cu	E
	Lysine		Mg	Mn	K
	Methionine		S	I	C (Ascorbic acid)
	Phenylalanine		P	Fe	B_1 (Thiamine)
	Threonine		Cl	Se	B_2 (Riboflavin)
	Tryptophan			Si	B_3 (Niacin)
	Valine			Mo	B_5 (Pantothenic acid)
				Co (in B_{12})	B_6 (Pyroxidine)
				B[a)]	B_7/H (Biotin)
				Ni[a)]	B_9 (Folic acid, folacin)
				Cr[a)]	B_{12} (Cobalamin)
				V[a)]	
				As[a)]	
				Li[a)]	
				Sn[a)]	

a) Not generally recognized as essential but some supporting evidence published.

(between 1768 and 1779) [2]. It was not until later that scientists established the definitive link between scurvy and vitamin C (ascorbic acid) deficiency. Chemistry not only identified these critical elements for human health but defined what is considered "essential" for sustaining life (see Table 2.1) [3].

Agriculture, the source of most food, became a science when Justus von Liebig (1803–1873) discovered the essential nutrient elements in plants. Fritz Haber (1868–1934) and Carl Bosch (1874–1940) invented ammonia synthesis that produced nitrogen fertilizers. Together with Gregor Mendel (1822–1884), the father of genetics and Martinus Beijerinck (1851–1900) discoverer of biological nitrogen fixation by legumes, the chemical foundations of agriculture were established. The International Union of Pure and Applied Chemistry devoted its second CHEMRAWN (Chemical Research Applied to World Needs) conference, held in Manila, Philippines in 1982, to chemistry and world food supplies [4]; followed by CHEMRAWN XII (Role of Chemistry in Sustainable Agriculture and Human Well-being in Africa) held at Stellenbosch, South Africa in 2007, reflecting the close relationship between chemistry and agriculture.

At the root of these chemical compounds is food, the backbone of human survival and evolution. Yet, today, we find that food remains an issue – either too much or not enough – in the continuing development of the human race. This chapter will explore how chemistry has historically influenced food security through food production, its access and nutrition. We will also explore how chemistry continues to provide and contribute to technology that defines the future of food and, hopefully, provides enough high quality food to sustainably nourish the estimated 9 billion people who will live on this planet by 2050.

2.2
Global Hunger and Malnutrition in the World Today

At the Millennium Summit in September 2000, the largest gathering of world leaders in history adopted the UN Millennium Declaration, committing their nations to a bold global partnership to reduce extreme poverty and to address a series of time-bound health and development targets [5]. These targets, the Millennium Development Goals (MDGs) and their indicators could be used to set benchmarks and monitor country-level progress. Among these MDGs is a commitment to reduce the proportion of people who suffer from hunger by half between 1990 and 2015 [6]. In 2010, many countries remain far from reaching this target, and ensuring global food security persists as one of the greatest challenges of our time. In the developing world, reductions in hunger witnessed during the 1990s have recently been eroded by the global food price and economic crises [7], which together added 105 million to the ranks of the hungry since 2008 [8].

There is clearly much progress to be made in addressing both hunger and undernutrition. As of 2009, 1 billion people are hungry, and 200 million children under five years of age are undernourished, with the majority of these children living in just 36 countries [9]. Vitamin A and zinc deficiency alone contribute to over half a million child deaths annually – both deficiencies are amenable to simple, effective and low-cost interventions [9a].

The MDG1 hunger target has two specific measures to track success: the prevalence of underweight children under five years of age, and the proportion of the population below a minimum level of dietary energy consumption. Obtaining an accurate measure of progress towards the MDG1 hunger target, and “food security” is challenging, and these two measures of the MDG1 are flawed.

2.2.1
Progress on the Proportion of Children Who are Underweight

Nonetheless, in the developing world, the proportion of children under five years of age who are underweight, declined from 31% to 26% between 1990 and 2008 [7, 10]. The progress made to reduce the number of children who are undernourished is insufficient to meet the goal of cutting underweight prevalence in half globally. When taking the 2008–2009 financial and economic crises into account, the task will be more difficult, but not unachievable in some countries (Figure 2.1) [9c].

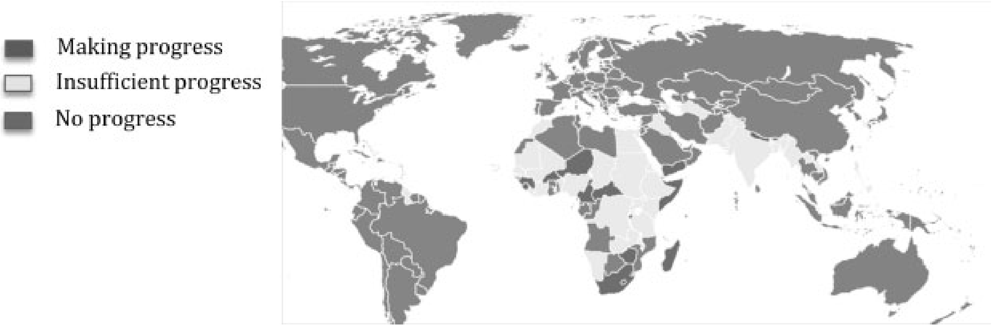

Figure 2.1 Country progress in meeting the MDG1 indicator for prevalence of children underweight (source [9c]). (Please find a color version of this figure in the color plates.)

2.2.2
Progress on the Proportion of the Population Who are Undernourished

The proportion of undernourished persons in developing countries, as measured by the proportion of the population below the minimum level of dietary energy consumption, decreased from 20% to 17% (a decrease in absolute numbers of 9 million) in the 1990s but both the proportion and absolute numbers have reversed course and increased in 2008 due to the food price crisis, which has severely impacted sub-Saharan Africa and Oceania regions [7]. Sub-Saharan Africa has the highest proportion of undernourished with 29% followed by Southern Asia, including India, at 22% [7].

2.3
Hunger, Nutrition, and the Food Security Mandate

What does it mean to be hungry? In its common usage, hunger describes the subjective feeling of discomfort that follows a period without eating [11]; however, even temporary periods of hunger can be debilitating to longer term human growth and development [12]. *Acute hunger* is when lack of food is short term and is often caused by shocks, whereas *chronic hunger* is a constant or recurrent lack of food [13]. The term *undernourishment* defines insufficient food intake to continuously meet dietary energy requirements [8] with FAO further defining hunger as the consumption of less than 1600–2000 calories per day.

What does it mean to have enough to eat?

The definition of food security set out at the 1996 World Food Summit stated that “food security exists when all people at all times have both physical and economic access to sufficient food to meet their dietary needs for a productive and healthy life”.

Hunger often goes hand in hand with food security. The concept of food security goes beyond caloric intake and addresses both hunger and undernutrition [14]. Reducing levels of *hunger* places the emphasis on the quantity of food, and refers to ensuring a minimum caloric intake is met. Conversely, ensuring adequate *nutrition* refers to a diet's quality. A diet rich in proteins, essential fatty acids, and micronutrients has been proven to improve birth weight, growth, and cognitive development while leading to lower levels of child mortality [9a, 15]. A lack of these essential vitamins and minerals often results in "hidden hunger" where the signs of malnutrition and hunger are less visible in the immediate sense.

The achievement of food security depends upon three distinct but connected pillars. The first is *food availability*, which refers to ensuring sufficient quantity and diversity of food is available for consumption from the farm, the marketplace or elsewhere. Such food can be supplied through household production, other domestic output, commercial imports, or food assistance. The second, *food access*, refers to households having the physical and financial resources required to obtain appropriate foods for a nutritious diet. Access depends on income available to the household, on the distribution of income within the household, and on the price of food. The third, *food utilization*, implies the capacity and resources necessary to use food appropriately to support healthy diets, including sufficient energy and essential nutrients, potable water and adequate sanitation. Effective food utilization depends, in large measure, on knowledge within the household of food storage and processing techniques, basic principles of nutrition and proper child care, and illness management [14a]. Most precisely, the concept of "nutrition security" has been defined as "having adequate protein, energy, vitamins, and minerals for all household members at all times" [16].

For many years, food security was simply equated with enhancing the availability of food, and was linked to innovations in agricultural production. In many developing countries, agriculture remains the backbone of the rural economy. Increasing agricultural outputs impacts economic growth by enhancing farm productivity and food availability [17], while providing an economic and employment buffer during times of crisis [8]. In the 1970s and 80s, large investments in agriculture, technology, roads and irrigation led to major improvements in food production, particularly in Asia and Latin America. Chemistry was at the heart of some of these tools and technologies. During this period the proportion of official development assistance devoted to agriculture peaked at 15–20% [8]. Over the past decade, decreasing levels of agriculture aid and investment, particularly the dismantling of input, credit and market subsidies, reduced public support for research and extension, and declining infrastructure investments have been linked to rising numbers of people being undernourished [8]. The reverse relationship has also been suggested, with hunger and undernourishment carrying substantive economic and social costs with reduced labor productivity, investment in human capital, and escalating poverty [18].

While food availability is clearly important to achieving food security, having the means to effectively access and utilize food remains central to good nutrition. This wider focus is important. There is a growing recognition that food security must

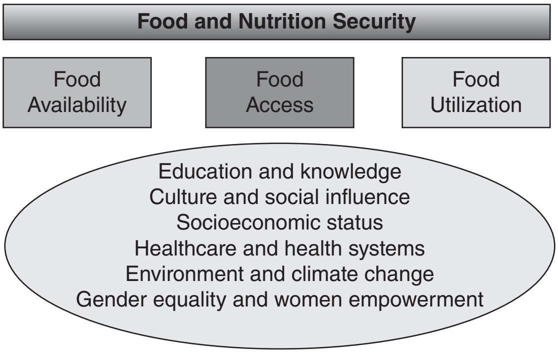

Figure 2.2 The determinants of food security (source [19]).

be viewed as inseparable from the other MDGs – and that addressing poverty, education, health and basic infrastructure are also critical. This interdependence is illustrated in Figure 2.2 [19] which makes the point that achieving sustainable gains in reducing hunger and undernutrition, and improving food security, will depend fully on concerted and synergistic efforts on a number of fronts.

2.4
Chemistry's Influence on the Pillars of Food Security

2.4.1
Food Availability

It is estimated that to meet the population's demands of 2050, a doubling of grain production will be needed, however, yield increases of the world's cereals have begun to stagnate [20] and yields in many regions of the world suffer from nutrient limitations and lack of access to irrigation. Future production will be further threatened by increased soil degradation, climate change, and the increased volatility of oil production and its impact on fertilizer prices [21].

In many poor rural settings, addressing hunger is inextricably linked to improving soil fertility and crop management [22]. Soil chemistry and applications play a critical role in developing soil and crop management practices through enhanced understanding of soil processes, plant nutrition, fertilizer production, development of improved crop varieties and methods for controlling pests and diseases.

2.4.2
Chemistry and the Green Revolution

The 1960s was a decade of despair with regard to the world's ability to cope with the food–population balance, particularly in developing countries. Most of the lands suitable for agriculture in Asian countries were cultivated while population growth rates accelerated, owing to the rapidly declining mortality rates that resulted from advances in modern medicine and health care. Massive starvation was predicted and international organizations and concerned professionals raised awareness of the ensuing food crisis and mobilized global resources to tackle the problem [19, 23].

Fortunately, large-scale famines and social and economic upheavals were averted, thanks largely to the marked increase in cereal grain yields in many Asian developing countries that began in the late 1960s [24]. This phenomenon – coined the "Green Revolution" – was due largely to the development and widespread adoption of chemical-based technologies. Key was the development and extension of genetically improved high-yielding varieties of cereal crops that were responsive to the application of advanced agronomic practices, including, most importantly, fertilizers and improved irrigation [23a, 24b]. Norman Borlaug, one of the fathers of the Green Revolution, summed up the role that nitrogen (N) fertilizer played in this grand agricultural transformation by using a memorable kinetic analogy: "If the high yielding dwarf wheat and rice varieties are the catalysts that have ignited the Green Revolution, then chemical fertilizer is the fuel that has powered its forward thrust..." [25]. The fuel for the transformation was made available by Haber's brilliant discovery of ammonia synthesis from its elements, in 1909, and the extraordinarily rapid commercialization of this invention, led by Bosch, that made large-scale production of ammonia possible by 1913 [26]. As shown in Figure 2.3, rapid post-1950 diffusion of N-fertilizer applications had increased

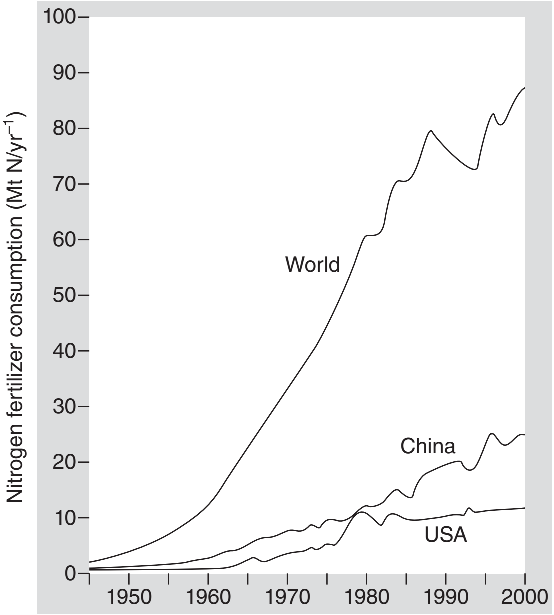

Figure 2.3 Consumption of nitrogenous fertilizers, 1950–1999 (source [27a]).

their worldwide use to nearly 80 million tonnes (Mt) by the late 1980s and, after a period of stagnation (related to the fall of the USSR), to 87 Mt N in the year 2000 [26, 27]. The projected demand for nitrogen from chemical fertilizer is estimated to increase to 236 MT in 2050 [27b].

The Green Revolution had a tremendous impact on food production and socioeconomic conditions. Between 1966 and 2005, food production in South Asia increased by 240% [28]. Applying advanced technology to high-yielding varieties of cereals caused the marked achievements in world food production. The gradual replacement of traditional varieties of rice, maize and wheat – crops which account for almost 50% of calories in most diets – by improved varieties, and the associated improvement in farm management practices, had a great effect on the growth of rice, wheat and maize output, particularly in Asia. For example, the average rice yield in South Asia increased by 240% from 1966 to 2007. During the same period, daily caloric intake per capita improved on average by approximately 25% [28].

In addition to fertilizers, pesticides have also played an important role in increasing agricultural production during the Asian Green Revolution. Insect pests, diseases, weeds and rodents are serious constraints to agricultural production, especially in the humid tropics. Scientific efforts to remove these constraints have focused on the breeding of resistant varieties of crop plants, as well as on the development of pesticides, insecticides and herbicides and integrated pest management strategies. In developing countries, most of the pesticides are, however, applied to exported crops, such as cotton and tropical fruits, rather than to locally consumed food crops.

In this way, the Green Revolution was able to address food availability challenges. The widespread adoption of high-yielding varieties has helped many Asian and Latin American countries to meet their growing food needs from productive lands and has reduced the pressure to open up more fragile lands. Despite its achievements, the first Green Revolution did not solve all food and nutrition security issues, partly because the efforts emphasized the food availability component of food security over the food access, food utilization and sustainability components, resulting in the neglect of core nutrition elements and environmental challenges. Although massive efforts were taken to decrease hunger in India, 50% of children across South Asia continue to suffer from undernutrition [9c, 29]. Further, excessive use of fertilizers and pesticides, as well as the monoculture of a few crop cultivars, created serious environmental problems, including the breakdown of resistance and the degradation of soil fertility [24b, 30]. It is now critical that chemical science invests and takes a leading role in cross-disciplinary efforts to predict when and where the use of agrochemicals and chemical-based technologies are pushing food production systems over sustainable boundaries [31], and to develop innovative strategies that can enhance social, environmental and economic sustainability of food systems.

While Asia and Latin America dramatically increased their agricultural productivity over the past 40 years, Africa's agricultural growth stagnated due to high transport costs, poor infrastructure, low levels of fertilizer use and the dismantling of public agricultural institutions for research, extension, credit and marketing [11,

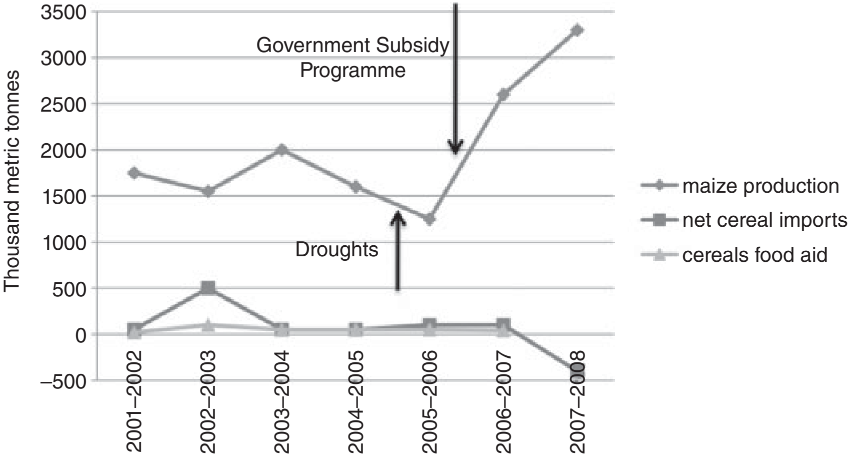

Figure 2.4 Maize production and cereal trade in Malawi (1990 to 2007) (source [34]).

32]. However, after decades of neglect of Africa's agricultural systems, a Green Revolution for Africa is emerging and there is now optimism about sub-Saharan Africa's ability to rapidly increase its agricultural productivity. This is partly due to some key successes – at the local and national levels – of policies that support smallholder farmers. In Malawi, because of a smart input subsidy program implemented by the government, maize harvests have greatly surpassed those of previous years, turning that country from a recipient of food aid into a food exporter and food aid donor to neighboring countries [33] (Figure 2.4).

Micronutrient fertilizers

Under certain soil conditions, the use of micronutrient fertilizers, in balanced combination with macronutrient fertilizers, has promising potential to increase production, disease resistance, stress tolerance, and the nutritional quality of crops. The increase in yield from the use of micronutrients deficient in the crops, notably zinc and boron, should compensate their cost and can also make the use of macronutrient fertilizers more cost effective as a package of balanced nutrients.

As more money and attention galvanizes much-needed action on the African Green Revolution, a vigorous debate is required to ensure that the mission of improving food security on the world's poorest continent is achieved in the most effective, comprehensive and inclusive manner possible. The African Green Revolution cannot be limited to increasing yields of staple crops but must be designed as a driver of sustainable development, which includes nutrition elements. Advances in chemistry can again play a pivotal role in this process. For example, our understanding of human N (protein) needs has undergone many revisions, and, although some uncertainties still remain, it is clear that average protein intakes are excessive in rich countries and inadequate for hundreds of millions of people in Asia, Africa, and Latin America. More dietary protein will be needed to eliminate these disparities but the future global use of N fertilizers can be moderated not just by better agronomic practices but also by higher feeding efficiencies and by gradual changes of prevailing diets. As a result, it could be possible to supply adequate nutrition to the world's growing population without any massive increases in N inputs. The addition of micronutrients to fertilizers is another area of interest [3, 35].

2.4.3
Genetically Engineered Crops and Food Production

A highly debated topic and example of a current technology at the crossroads of agriculture and chemistry is genetic engineering (GE), a modern technology for modifying crops and livestock. GE is one of several tools in the modern crop biotechnology kit and allows the introduction of genes from the same species or from any other species, including species that are beyond the normal reproductive range of the plant, into the plant or animal. The need to develop new crop varieties that are adapted to local conditions, conducive to sustainable agriculture, and remain high-yielding in the absence of irrigation or large inputs of petrochemicals, is an exceptionally tall and urgent order. Many plant scientists believe that GE can contribute significantly to achieving these goals [36]. However, there are a multitude of concerns about the effects of GE crops on human health, environment, social well-being and ethics which are fueling a polarized debate. One side perceives that excessive regulation is slowing the delivery of benefits [37]; the other is concerned that adoption is proceeding hastily and without adequate safeguards [38]. This is embedded in a multidimensional debate, including scientific, social, economic, political and ethical issues.

GE crops and foods have been commercially available in the US since 1995 and their adoption around the world followed, showing increases each year (Figure 2.5). In 2008, the global area of commercially grown GE crops was 125 million hectares, involving 25 countries [40]. The four primary GE crops in terms of land area are soybean, maize, cotton and canola (oilseed rape). In 2008, GE crops were being grown on 9% of the global arable land, 70% of soybean cropland was planted with a GE variety, for maize cropland this was 24%, for cotton 46% and for canola 20% [40], in total corresponding to 40% of the cropland of these main crops.

Nutritionally improved GE seeds

The first use of GE to alter nutritional quality was the introduction of three genes into rice to create the much publicized *Golden Rice* variety, enriched in vitamin A. Many more GE crops with enhanced nutritional value have followed, such as increased protein quality and levels in maize, increased calcium levels in potato and increased folate levels in tomato. However, none of these crops is commercially available yet.

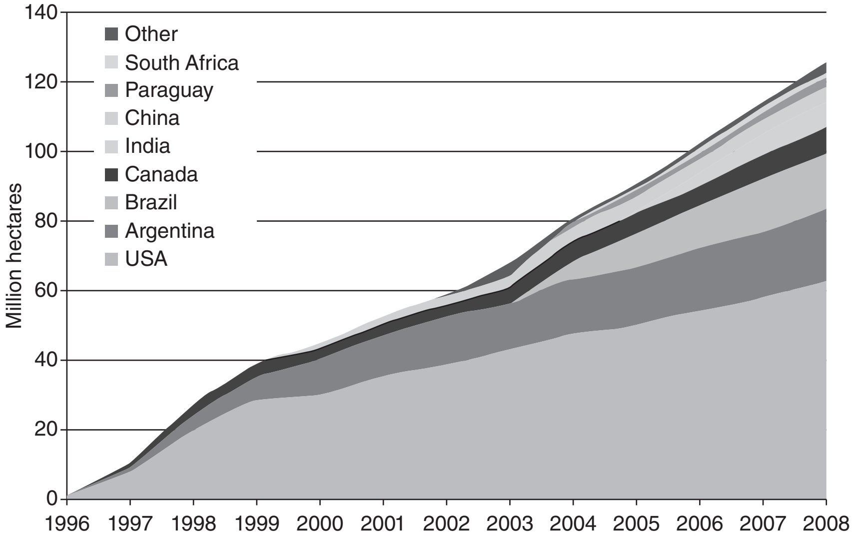

Figure 2.5 Million hectares of GE crops per country (source [39]). (Please find a color version of this figure in the color plates.)

Despite sizeable GE crop acreage, the current diversity of crop types and traits in commercial production is limited. Nearly all major-acreage, commercial releases of GE crops are at present based on pest protection via genes from *Bacillus thuringiensis* (Bt), a widespread soil bacterium that produces insecticidal proteins called Bt toxins, or herbicide tolerance (HT), or a combination of both [40, 41]. HT crops are tolerant to certain broad-spectrum herbicides such as glyphosate and glufosinate, which are more effective, less toxic, and usually cheaper than selective herbicides. By cutting the costs and labor of weed or insect control, these first generation commercial pest and/or herbicide tolerant GEs have been shown to provide a tangible economic benefit to farmers [37c, 41, 42], to result in time savings, increased ease of agricultural practices and reduction in yield losses and pesticide use [37c, 41–43].

The average reduction in pesticide use by using Bt crops has been shown to vary from 0% for Bt maize in Argentina to 77% for Bt cotton in Mexico [37c]. Average increases in *effective yield* – through reduction of yield losses – by using Bt crops vary between 0% for Bt cotton in Australia to 37% for Bt cotton in India [37c]. For HT crops, in most cases no increase in yield is observed compared to conventional crops [37c].

Although commercialized GE crops are limited in trait diversity, proof-of-concept for many other traits has been reported in laboratory experiments and small-scale field trials. While the first generation of commercialized crops focused largely on input agronomic traits, the coming generation of crop plants can be grouped into four broad categories of impact: *agronomic performance, environment, human health* [44] *and rural livelihood.*

2.4.4
Food Access

Food access involves whether households have the physical and financial resources required to obtain appropriate food for a nutritious diet. This access depends on income available to the household, on the distribution of income within the household, and on the price of food. Access also depends on what happens to the food after production, such as during post-harvest storage.

2.4.4.1 Post-Harvest Treatment and Storage

One of the main causes of food insecurity in Africa is the high prevalence of storage pests. Maize is an excellent food source and an ideal breeding site for storage pests [45]. Pests can be defined as those organisms that cause damage resulting in economic loss to maize and other plants in the field or in storage [46]. The Larger Grain Borer (LGB, Figure 2.6), which is sometimes referred to as the Greater Grain Borer (GGB), and given names like "Osama" is the single most serious pest of stored maize and dried cassava roots (chips). The primary host is maize, in particular maize on the cob, both before and after harvest. LGB destroys maize giving unusable flour (Figure 2.7). LGB also bores into non-food substances such as wood, bamboo, and even plastic, which poses a challenge to controlling the pest.

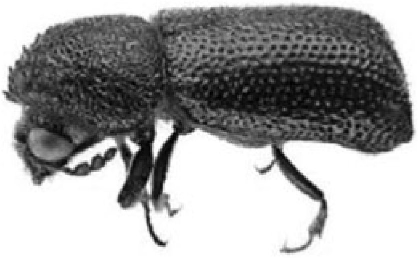

Figure 2.6 The Larger Grain Borer (source [45]). (Please find a color version of this figure in the color plates.)

Figure 2.7 Maize destroyed by the Large Grain Borer to flour (source [45]). (Please find a color version of this figure in the color plates.)

According to national maize experts, maize losses due to storage pests range from 30–60% in Malawi, Tanzania and Kenya, much of which is attributed to the presence of the Large Grain Borer and these figures far exceed what is currently recorded in the literature. Maize losses experienced by farmers are variable, but farmers in all countries of the study confirmed experiencing losses, even if they used inorganic or organic storage insecticides, and all confirmed that losses can be up to 100% if maize is not protected with insecticides before storing. Also, effectiveness of some insecticides is questionable. There are cases of purportedly effective insecticides bought direct from the importing company. It was even demonstrated by one of the company's experienced sales representatives, but the maize treated by the farmers and the maize treated for demonstration by the representative was destroyed by LGB [45].

It is apparent that maize storage is a crucial component of ensuring greater food security and should be included in efforts by research institutes, national governments and development partners, especially in countries where such efforts have yielded substantial returns in maize or other food crop productivity. Recommendations and management strategies form an integrated approach to the management of storage pests and include chemical-based technologies, particularly drying techniques, drying cribs and treatment of maize, before and during storage, with insecticides (Figure 2.8). However, due to lack of awareness and access to proper technologies, farmers end up selling their maize soon after harvest, only to buy it back from the same people at more than twice the price they sold it for just a few months after harvest, resulting in a continual poverty trap. If efforts to increase food security included storage, and farmers were able to store their maize properly, they would save between US$10 to US$20 per bag of maize needed for household consumption throughout the year. These may appear like small savings, but from analysis of family sizes in rural sub-Saharan Africa and the corresponding maize required to feed larger traditional families, these translate into huge savings per

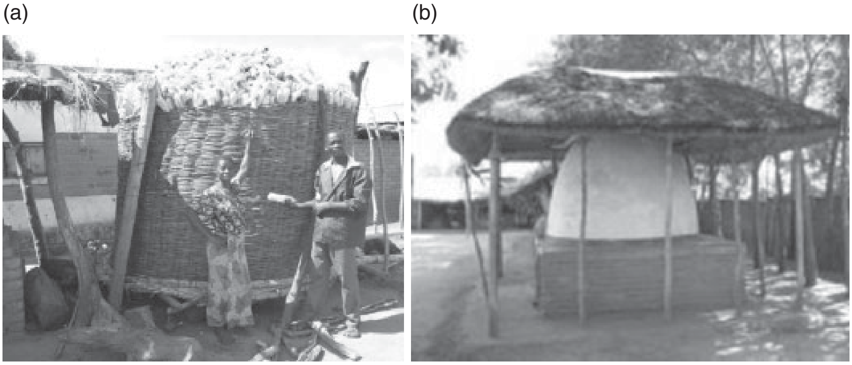

Figure 2.8 Traditional granary (a) and improved granary/crib (b) in the Millennium Village Project Mwandama, Malawi (source: MDG Centre East and Southern Africa). (Please find a color version of this figure in the color plates.)

family. Furthermore, storage pests, in particular LGB, and in combination with other pests such as Maize weevils, cause substantial losses at national levels, which translates, approximately, to between US$150 and US$300 million, money which could be used to provide other essential in-country services [45].

A case study: millennium villages in sub-Saharan Africa

The Millennium Villages Project was initiated in 2005 to accelerate progress towards the MDG targets, including MDG 1 – to eradicate extreme poverty and hunger. The Millennium Villages are situated in "hunger hotspots", where at least 20% of children are malnourished and where severe poverty is endemic. The countries where Millennium Villages are located are Ethiopia, Ghana, Kenya, Malawi, Mali, Nigeria, Rwanda, Senegal, Tanzania, and Uganda. They were chosen to reflect a diversity of agro-ecological zones, representing the farming systems found in over 90% of sub-Saharan Africa and are demonstration and testing sites for the integrated delivery of science-based interventions in health, education, agriculture and infrastructure. Within the Project, hunger and undernutrition is being addressed with an integrated food- and livelihood-based model that delivers a comprehensive package of development interventions.

By supporting farmers with fertilizers, improved crop germplasm and intensive training on appropriate agronomic practices, average yields of 3 t ha^{-1} were exceeded in all sites where maize is the major crop, compared to average cereal yields of less than 1 tons (t) hectare $(ha)^{-1}$ before intervention [47]. Households produced enough maize to meet basic caloric requirements, with the exception of farms smaller than 0.2 ha in Sauri, Kenya. Value to cost ratios of 2 and above show that the investment in seed and fertilizer is profitable, provided surplus harvests were stored and sold at peak prices [47]. Increased crop yields are the first step in the African Green Revolution, and must be followed by crop diversification for improving nutrition and generating income and a transition to market-based agriculture. A multi-sector approach that exploits the synergies among improved crop production, nutrition, health, and education is essential to achieving the MDGs.

Key Interventions in Food Production in the Millennium Villages include:

- ***Soil rehabilitation techniques.*** Replenish nutrients in the soil with mineral fertilizers, nitrogen-fixing legumes, and other organic materials, and, by returning crop residues to the soil, and soil conservation techniques, reduce run-off and erosion and maintain the investments in soil rehabilitation.
- ***Access to improved seeds.*** Provide farmers with access to and information about improved seeds for basic food crops, livestock, grain legumes, root and tuber crops, vegetable, tree, and fodder crops, as well as developing, where appropriate, the capacity of community members to produce their own seed or planting materials using seed multiplication plots, seed orchards, and nurseries.
- ***Small-scale irrigation systems.*** Promote efficient irrigation technologies for supplementation of rain-fed crops and increased and off-season production of cash crops. Train farmers and other groups in techniques such as rainwater harvesting and storage, gravity, and low-pressure irrigation systems, and improving existing irrigation systems; provide access to equipment required for these techniques.

- ***Grain storage facilities.*** Minimize post-harvest losses and store food beyond subsistence needs by training farmers and farmer groups in the construction of household and community grain storage structures. *Creation of cereal banks* by communities to store surplus for later sales at better prices.
- ***Agricultural extension services.*** Provide field training on land preparation, plant spacing, fertilizer placement, and integrated soil fertility management practices, including agro-forestry. Provide information to agricultural extension officers to ensure that they have the latest and most appropriate information on soil health, small-scale water management, improved seeds, livestock, agro-forestry, and other locally relevant agricultural techniques.
- ***Crop diversification for income generation and nutritional security.*** Promotion of crops that help improve household nutrition. Crops include vegetables, fruits, grain legumes, livestock, and dairy. This diversification strategy must include nutrition education programs around the various crops.
- ***Farmer organizations.*** Help establish and train village organizations to develop organized systems to sell products to more distant markets, engage with microfinance institutions to purchase farm inputs, and promote other skills required for developing commercial farming enterprises.

2.4.5
Food Utilization

To have food available and accessible to eat, whether purchased at the market or grown at home, is not the sole solution to food security. A person's body must be in good physical condition in order to properly use the food. This is termed food utilization – the ability to use food efficiently in order to live life to the fullest. Focusing on the individual level, food utilization also takes into consideration the biological utilization of food. Biological utilization refers to the ability of the human body to take food and convert it into energy, either used to undertake daily activities, or stored. Utilization requires not only an adequate diet, but also a healthy physical environment, including safe drinking water, adequate sanitation and hygiene, decreased burden of infectious disease, and the knowledge and understanding of proper care for oneself, for food preparation and safety.

2.4.5.1 Balanced Diets and Utilization of Nutrients: The Chemical Components

Chemistry has taught us that not only is it essential that our bodies absorb the nutrients from foods that we eat, but that the chemical composition of the foods consumed in specific combinations and the quality of the diet are critical in meeting dietary needs. The role of essential nutrients in human health and the synergies in their physiological functions are being increasingly recognized and support the notion that nutrient deficiencies rarely occur in isolation [48]. The challenge is to provide the adequate amount and diversity of nutrients required for a complete human diet. This urges a multidimensional approach. Optimizing for nutrient diversity can be presented schematically as maximizing the various

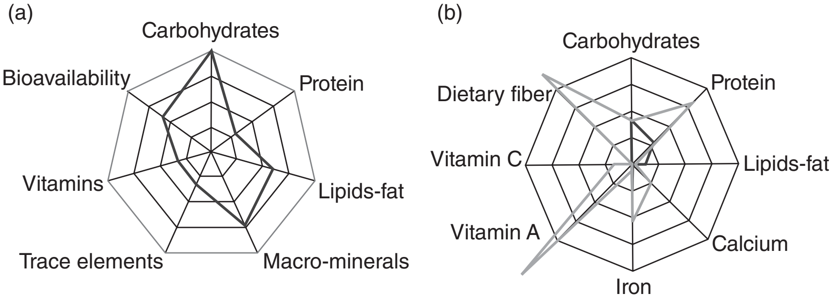

Figure 2.9 Ecological spider web presenting diversity requirements in a human diet. (a) Nutrient composition of an ideal diet that meets all nutritional needs is shown in pink. An example of nutrient composition of a diet that meets carbohydrate demand but lacks protein and micronutrients or trace elements is shown in blue. (b) Nutrient composition data of three food crops are shown as % of daily requirement (100%). The blue line represents one cup of white corn (166 g), the green line one cup of black beans (194 g), and the orange line one cup of pumpkin (116 g) (nutrition facts from http://www.nutritiondata.com). The spiderdiagram shows the complementarity between the three food crops for carbohydrates, proteins, dietary fiber, and vitamin A (source [49]). (Please find a color version of this figure in the color plates.)

arms of an ecological spider diagram, as illustrated in Figure 2.9. Figure 2.9a shows the nutrient composition of an ideal diet that meets all nutritional needs, shown in pink. An example of nutrient composition of a diet that meets carbohydrate demand but lacks protein and micronutrients or trace elements is shown in blue. In Figure 2.9b, nutrient composition data of three food crops are shown as % of daily requirement (100%). The blue line represents one cup of white corn (166 g), the green line one cup of black beans (194 g) and the orange line one cup of pumpkin (116 g). The spider diagram shows the complementarity between the three food crops for carbohydrates, proteins, dietary fiber, and vitamin A and the importance of the chemical composition of foods in meeting the nutritional requirements of the diet.

On a global basis, plants provide approximately 65% of the world supply of edible protein whereas animal products contribute 35% [50], much coming from cereal grains. Important differences among and between food products are the concentrations of proteins and the essential amino acids they contain. Eight amino acids are generally regarded as essential for humans: isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine. In addition, arginine, cysteine, histidine and tyrosine are required by infants and growing children. These amino acids are considered essential because the body does not synthesize them, making it essential to include them in one's diet in order to obtain them.

Diets rich in cereals and of vegetable origin do not contain all the essential amino acids necessary for daily consumption and requirements. Instead, near-complete proteins are found in plant sources. In contrast, animal sources such as meat, poultry, eggs, fish, milk, and cheese provide all of the essential amino acids but are not consumed on a daily basis by the majority of the global population (particularly the developing world) due to cost and supply. Often in the developing

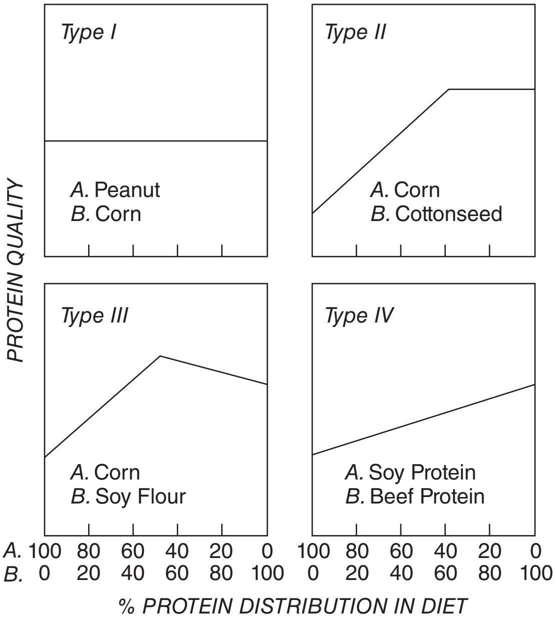

Figure 2.10 Protein complementation and four response types (source [50]).

world, the diet is not adequate in quality protein when consumed in the traditional sense as the diet is made up mainly of plant-based sources. This often leads to children with protein energy malnutrition and faltering growth, particularly among children aged 6 to 24 months [51]. Yet, despite this challenge, it is not necessary to consume animal sources containing complete proteins as long as a reasonably varied diet is maintained and other sources rich in proteins, such as legumes which contain essential amino acids, provide adequate full complementation of the essential amino acids and protein quality for adequate health and nutrition. By consuming a wide variety of plant foods, a full set of essential amino acids will be supplied and the human body can convert the amino acids into proteins. This is at the core of the chemical composition of diets.

To consume a varied diet made up mainly of plant sources, it is important to think about chemical composition and combinations of food. When two dietary proteins are combined, different types of responses result [50]. Four types have been classified (Figure 2.10) through chemical bioassay studies. Type I indicates when no protein complementary effects occur. This can occur with peanuts mixed with corn diets in which both are deficient in essential amino acids. This is obviously not an optimal combination to provide protein needs for the day. Type II is when two sources of food such as corn and cottonseed have a limiting amino acid, in this case lysine. Some of the essential amino acids are met, but not completely. Type III demonstrates a true complementary effect working synergistically to meet the needs with corn and soybean. The sum of both meets the protein needs. Soy is considered a high quality protein source. Type IV occurs when both sources have a common amino acid deficiency and is not considered ideal [50].

2.4.5.2 **Antinutrients**

With plant foods being the predominant source of the diet in much of the poor world, antinutrients and promoters contained in these plant foods should be taken into consideration with regard to bioavailability of nutrients to humans. Most antinutrients in foods inhibit the absorption of micronutrients that are essential for growth and are often deficient in the developing world – predominantly iron and zinc. Antinutrients include phytic acid, fiber, tannins, oxalic acid, goitrogens and hemagglutinins [52]. Phytic acid or phytates, one of the greater concerns, are often found in whole legumes, and cereal grains – the staples of the diets in resource-poor communities.

Several traditional food processing and preparation methods, that work on the basics of chemistry, are often used at the household level to enhance the bioavailability of micronutrients, including mechanical processing, soaking, fermentation and germination or malting [53]. For example, boiling of tubers can induce moderate losses of phytic acid [54]. Fermentation can also induce phytate hydrolysis via the action of microbial phytase enzymes which hydrolyze phytate to lower inositol phosphates [55]. This has been done in maize, soy beans, sorghum, cassava, cocoyam, cowpeas and lima beans, all common foods in the developing world. Low-molecular weight organic acids such as citric acid can increase fermentation and enhance the absorption of zinc and iron [56].

Cassava is an important tropical root crop providing energy to approximately 500 million people (Figure 2.11). The presence of the two cyanogenic glycosides, linamarin and lotaustralin, in cassava is a major factor limiting its use as food and can be toxic. Traditional processing techniques practiced in cassava production are known to reduce the cyanide chemical in tubers and leaves. These including sun drying, soaking followed by boiling and fermentation, as used for traditional African cassava end products such as gari and fufu. The best processing method for the use of cassava leaves as human food is pounding the leaves and cooking the mash in water [57].

Figure 2.11 Cassava in Africa (source: Nestle). (Please find a color version of this figure in the color plates.)

2.4.5.3 **Fortification of Food Vehicles: One Chemical at a Time**

Food fortification is one of the food-based strategies for preventing micronutrient deficiencies. Currently, over 2 billion people globally are deficient in micronutrients, and many of these are women and children [9a, 9c]. In developing countries, fortification is increasingly recognized as an effective medium- and long-term and accessible approach to improve the micronutrient status of communities [58], and is considered cost effective. Fortification does not require changes in the dietary habits of the population, can often be implemented relatively quickly, and can be sustainable over a long period of time. It is considered one of the most cost-effective means of overcoming micronutrient malnutrition [18a].

Improving foods for malnourished children

The Global Alliance for Improved Nutrition (GAIN) is working with governments, public–private partnerships, local companies, non-governmental organizations, and not-for-profit venture capitalists to improve infant and young child feeding through commercializing nutritious *fortified* food products, including fortified complementary foods, micronutrient powders and lipid-based nutrient supplements. One study done by Doctors without Borders showed that short-term supplementation of these fortified complementary feeding foods given to children who were not malnourished reduced the incidence of acute malnutrition in Niger.

Fortification is the addition of nutrients to commonly eaten foods such as flour, sugar, salt and cooking oil, to increase the consumption of essential micronutrients for health. The food that carries the nutrient is the vehicle; the nutrient added is the fortifier. Fortification of foods is aimed to provide levels of the nutrient (30 to 50% of daily requirements) at normal consumption of a food vehicle [58]. For decades, fortification has been widespread throughout the world. In the US, flour has been fortified and almost one quarter of iron intake comes from fortified sources, much from flour [59].

The selection of the right vehicle and the appropriate micronutrients is a precondition to assure success in addressing micronutrient deficiencies, although at times it can be difficult. Potential vehicles have a pyramid-type priority (Figure 2.12) in that stable foods form the base of the pyramid and will result in a broader dissemination of targeting a large portion of the population. Basic foods and value-added foods are also critical to ensure that all common products within the food chain with the potential to be fortified are targeted.

Successful fortification vehicles for vitamin A, a common deficiency in the developing world, include sugar, margarine and oil. For example, in Guatemala, national sugar fortification with vitamin A has eliminated vitamin A deficiency [60]. Iodization of salt has become the most commonly accepted method of iodine deficiency prophylaxis in most countries of the world. Its advantages include uniformity of consumption, universal coverage, acceptability, simple technology and low cost [18a]. 60 to 70% of all salt is now iodized [58]. During the past few years, attention has been given to the possible high prevalence of zinc deficiency

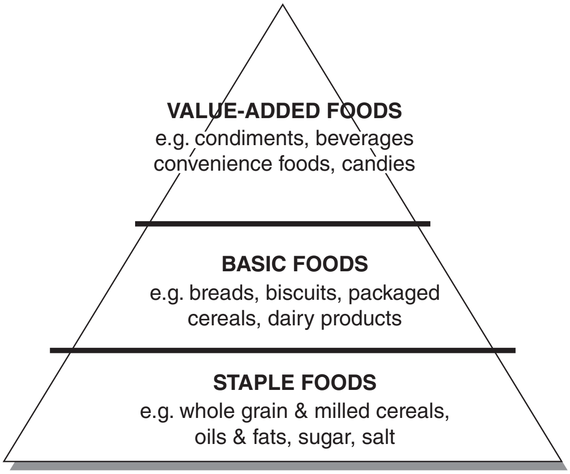

Figure 2.12 Food product pyramid for fortification (source [58]).

among children and its consequences. Results presented show that zinc has an impact on growth, especially in severely growth retarded and underweight children, and reduces morbidity. The role of seeds biofortified with zinc is being explored.

With this combination of technology and chemistry, food fortification is one of the most effective methods to eliminate micronutrient deficiencies, afflicting over 2 billion people worldwide. It has been shown to eliminate goiter, rickets, beriberi and pellagra from the western world [58] however, the focus should next be on the developing world where many remain hungry and undernourished.

2.4.5.4 **Improving Utilization through Modern Medicine: The Contribution of Chemistry to Basic Medicines**

Many of the determinants that impact food utilization are considered long-term poverty stricken determinants to poor nutrition. As shown in Figure 2.13, UNICEF's framework on the determinants of undernutrition, maternal and child care practices, which are associated with the situation of women in societies – education, knowledge, income generation, and reproductive practices [61] – are at the root of the problem.

Improving child feeding practices for young children is also a huge determinant of food utilization and child growth. This starts right at birth with exclusive breastfeeding and complementation of milk with food rich in energy and nutrients. Lastly, a robust primary health care systems approach must be in place to improve the nutritional situation and food utilization. Infectious diseases impede dietary intake and utilization, resulting in malnutrition. Consequently, one of the most important premises to improve nutrition is to control and prevent most common childhood infectious diseases by expanding immunization programs, providing diarrhea and malaria control and treatment programs, and decreasing parasitic

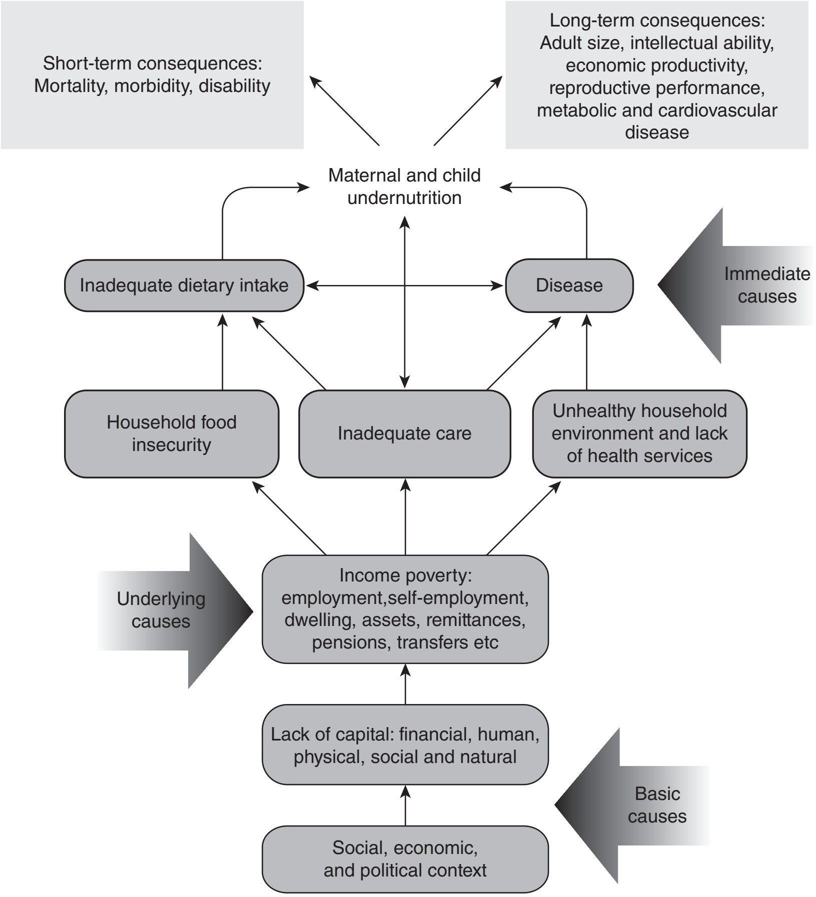

Figure 2.13 UNICEF's framework on undernutrition (source [61]).

burden. The backbone of some of these programs is water supply improvements and improving sanitation and hygiene in the home and schools.

One of the greatest contributions of chemistry to treating disease is through medicine. In the developing world, neglected tropical diseases such as worms, including ascaris roundworms, trichuris whipworms, and necator hookworms, in the intestines can contribute to anemia [62] and children suffer from deficits in physical growth, as well as reductions in intelligence, memory, and cognition [63]. The Global Burden of Disease caused by the three major intestinal nematodes is an estimated 22 million disability-adjusted life-years (DALYs) lost for hookworm, 10 million for Ascaris lumbricoides, 6 million for Trichuris trichiura, and 39 million for the three infections combined (as compared with malaria at 36 million) [63b]. Anorexia and perpetuated hunger, which can decrease intake of all nutrients in tropical populations on marginal diets, is likely to be the most important means by which intestinal nematodes inhibit growth and development.

In many cases, deworming once per year with a benimidazole anthelminthic drug such as albendazole or mebendazole, as discovered and made available by chemical companies, is sufficient [63b, 64]. These drugs are particularly effective for treating ascaris and trichuris worm infections [63b] and can be administered for as little as US$0.03 per person [65]. By treating preschool-age children and girls and women of childbearing age with these essential inexpensive medicines, morbidity and mortality can be prevented and the vicious intergenerational cycle of growth failure that entraps infants, children and girls and women of reproductive age in developing areas can be decreased [66].

2.5
Conclusion

Throughout the history of time, it is clear that chemistry has played a central role in the food and nutrition security agenda. Chemistry has been pivotal to food production from soil to seed, from pest control to human nutrition. Although food access is largely dependent on socioeconomic status, chemistry plays a role in improving the access to healthy foods through improved post-harvest storage loss. And lastly, chemistry is core to food utilization and combinations – by improved biofortification, food processing and essential medicines. Chemistry has contributed much to the food security agenda (Figure 2.14).

Evidence from the examples in this chapter suggests that food and nutrition security is complex, and requires efforts across a spectrum that includes enhancing food production while simultaneously increasing access and utilization with substantive political commitment to address the most vulnerable populations with an equitable, basic human rights approach. Chemistry plays a critical role in this spectrum and, in the future, requires a cross-sectoral approach.

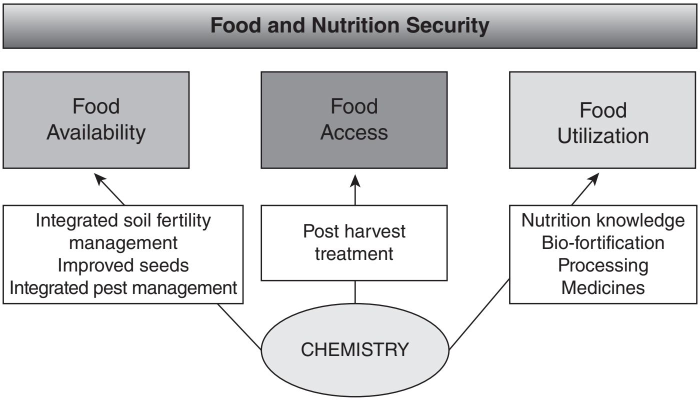

Figure 2.14 The role of chemistry in food and nutrition security.

Iyere [67] stated that “Sustainability and globalization therefore encompass addressing world hunger and poverty as well. Thus, there is a great need to gear chemistry contribution to mitigation of these problems to the chemistry of the past. In those times, agriculture was invigorated through the use of sensible chemistry and the development of the connections between chemistry, other disciplines, the environment, and daily life in such a way that interdisciplinary thinking and the relation of chemical concepts to societal issues became a way of life.”

In the model of food security itself along with Iyere’s thoughts on chemistry and sustainable development, addressing hunger requires a multi-disciplinary approach. Recent calls for greater attention to hunger and undernutrition highlight the importance of integrating technical interventions with broader approaches to address underlying causes of food insecurity–incorporating perspectives from agriculture, health, water and sanitation, infrastructure, gender and education–many rooted in the core science of chemistry. Such an approach would inherently build on the knowledge and capacities of local communities to transform and improve the quality of diets for better health and nutrition. Recent research has documented potential synergies between health and economic

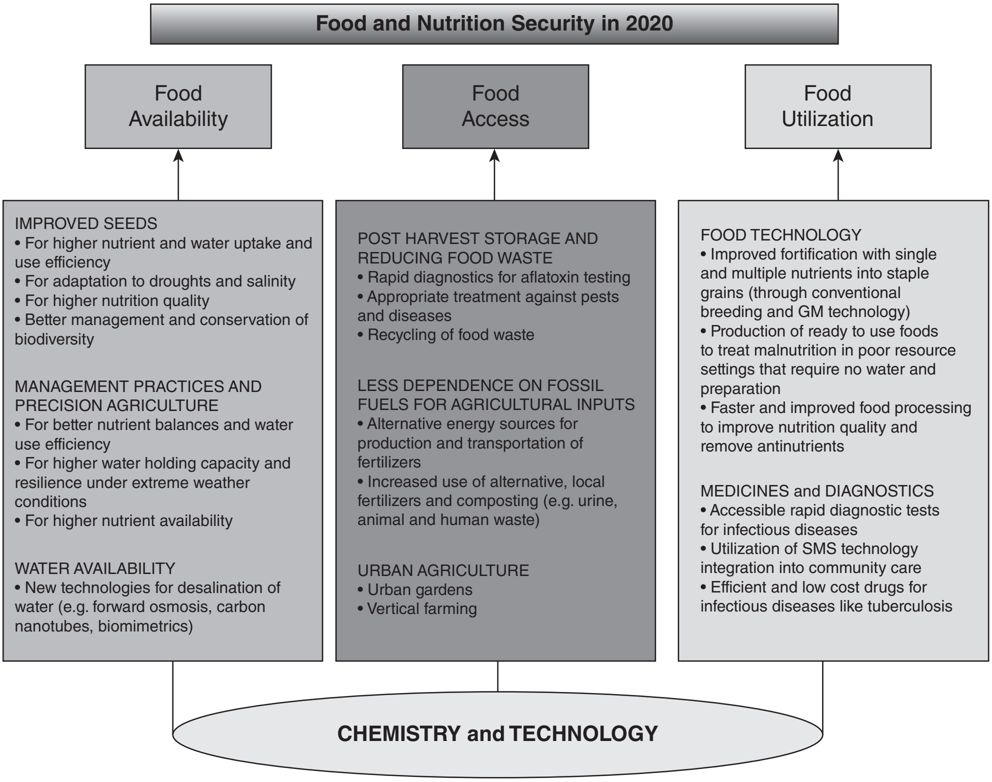

Figure 2.15 A 2020 vision for chemistry in achieving food security for all.

interventions, suggesting multi-sector approaches may generate a wider range of benefits than single sector approaches acting alone. The role of the chemical science and chemists will be challenged to work interdisciplinarily to address the global challenges that the world faces, and the hunger mandate calls for better tools and technologies to move forward.

In just 10 years from now, we envision that chemistry will become more and more important in all aspects of food security and nutrition (Figure 2.15). Although the numbers of those hungry and undernourished are staggering, the sciences such as chemistry can make huge strides to improve the situation. By 2020, much of the innovation and technology within chemistry can be earmarked and in motion to ensure that food security is achieved for all.

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