BACKGROUND INFORMATION

The first two modules in this Teacher's Guide introduce key agricultural methods, particularly selective breeding and genetic engineering. Modules 3 and 4 highlight some of the major reasons *why* we use these techniques (e.g., to decrease pest damage, to enhance nutrient profile).

All living things (plants, animals, and humans alike) need nutrients to survive. Nutrients in food contribute to cell-building and structural materials, regulate important functions in living tissues, and provide energy for growth and health. Nutrients are categorized as macronutrients (proteins, carbohydrates, and fats) or micronutrients (vitamins and minerals). Macronutrients are consumed/required at greater levels (g), micronutrients at lower levels (mg or µg). An "essential" nutrient is a nutrient that a plant, animal, or human must obtain from another source, because that organism cannot make it or cannot make enough of it for good health.

Human Nutrition

Every 5 years, human nutrition experts from different parts of U.S. society, including academia and government, review the latest nutrition information and issue a report called the *Dietary Guidelines for Americans* to promote good health. These *Guidelines* identify:

- target dietary goals for key micronutrients and macronutrients
- nutrients that Americans typically should aim to get more of (e.g., fiber, Vitamin D, calcium, potassium, iron)
- nutrients that people should aim to get less of (e.g., sodium, saturated fat, added sugars).

Key nutrients are shown on Nutrition Facts labels to help people make healthy food choices. For a more detailed supplementary curriculum on nutrition, see *Science and Our Food Supply: Using the Nutrition Facts Label to Make Healthy Food Choices*.

Essential nutrients for human diets are shown below. The exact amount recommended for individual people varies by age and gender, as well as with specific health conditions. For recommended nutrient intake for healthy individuals, see *Dietary Reference Intakes for Macronutrients, Vitamins and Micronutrients*.

Essential Nutrients for Humans

Macronutrients		Micronutrients	
Amino acids	**Fatty acids**	**Vitamins**	**Minerals**
Histidine	Linoleic acid	A	Ca (Calcium)
Isoleucine	Alpha-linolenic acid	B_1 (Thiamin)	Cl (Chlorine)
Leucine		B_2 (Riboflavin)	Cr (Chromium)
Lysine		B_3 (Niacin)	Cu (Copper)
Methionine		B_5 (Pantothenic acid)	Fe (Iron)
Phenylalanine		B_6	Fl (Fluoride)
Threonine		B_7 (Niacin)	I (Iodine)
Tryptophan		B_9 (Folate)	K (Potassium)
Valine		B_{12}	Mg (Magnesium)
		C (Ascorbic Acid)	Mn (Manganese)
		D	Mo (Molybdenum)
		E	Na (Sodium)
		K	Ni (Nickel)
		Choline	P (Phosphorus)
			S (Sulfur)
			Se (Selenium)
			Zn (Zinc)

BACKGROUND INFORMATION

Toxins and Anti-Nutrients

In addition to making many desirable nutrients, plants make toxins. They adjust their biochemistry to adapt to their environment, including defending themselves from predators. If consumed in sufficient quantities, some toxins can affect human or animal health. Through domestication, agriculturally important crops (including tomatoes and potatoes) have been bred to eliminate or reduce the level of relevant toxins. The word toxin is sometimes used to indicate substances of biological origin with toxic properties. These are also often referred to as toxicants.

Major toxins and their effects:

- Cyanogenic glycosides in cassava, sorghum, and bamboo shoots that are improperly prepared can result in unsafe levels of cyanide toxins harmful to people and/or animals.
- Curcubitacin in cucumber and squashes can cause acute gastrointestinal effects.
- Glycoalkaloids (e.g., solanine) in potatoes may induce gastrointestinal and systemic effects if consumed in high amounts. Potatoes/potato byproducts (e.g., skins where glycoalkaloids are concentrated) that are high in glycoalkaloids can be fatal for animals.
- Psoralen, a furocoumarin produced by some plants (celery and parsnips) that can harm the skin of people working in the sunlight.
- Coumarin (normally in sweet clover) can be metabolized by some fungi into dicoumarol, which causes prolonged clotting time and bleeding disease in cattle (rarely in horses).

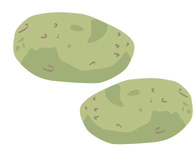
Plants also make substances that can affect the ability of human and animal digestive systems to extract the most nutrients out of food. These are called **anti-nutrients**.

Some major anti-nutrients and their effects:

- Glucosinolates in cruciferous vegetables can prevent iodine absorption.
- Lectins in legumes and whole grains can inhibit calcium, iron, phosphorous, and zinc absorption.
- Oxalates in leafy green vegetables and teas can inhibit calcium absorption.
- Phytates (phytic acid) in whole grains, seeds, legumes, and some nuts can decrease the bioavailability of iron, zinc, magnesium, and calcium.
- Saponins in legumes and whole grains can interfere with some nutrient absorption.
- Tannins in tea, coffee, and legumes can decrease iron absorption.

Human nutrition experts use dietary reference intake values to decide how much of a given nutrient people should consume (on average). These values include the adequate intake, recommended daily allowance, and tolerable upper limit for specific subgroups. Whether a substance is considered toxic depends on the dose (amount) consumed. The tolerable upper limit for an infant would be less than the limit for a grown adult, since the amount taken per body weight would be much higher for the infant. However, many desirable nutrients (including water) can be considered toxic if overconsumed. The phrase often used to describe this reality is "The dose makes the poison."

How Much is Too Much?



A 100-pound person would have to eat a pound or more of totally green potatoes to show low-grade symptoms of toxicity (nausea, diarrhea, vomiting).

Water needs vary with activity level. People also get water through various foods they eat. On an average day, adult men need 3.7 liters of water; adult women need 2.7 liters of water; and teenagers need about 2 liters. But, kidneys have a limit on how much water they can process each hour. Although highly unusual in healthy people, rapidly drinking excessive amounts of water can cause low sodium levels that lead to headaches, diarrhea, nausea, vomiting, and impaired brain function. Extreme overconsumption can be fatal.

Nutrient Deficiency

Throughout history, there have always been some people who had diseases and ailments associated with nutrient deficiency or malnourishment. Malnourishment is typically caused by a lack of access to enough nutritious food because of poverty, war, climate or weather conditions, and other economic factors. Circumstances that make it uncertain whether nutritionally adequate and safe food is available in socially acceptable ways is also called "Household Food Insecurity." Historically, the typical image of hunger was often an emaciated or very underweight person who also suffered from poverty. Today, hunger is still a problem, but the number of people who are both malnourished and overweight or obese has increased.

BACKGROUND INFORMATION

Fortified Bread Saves the South

In the late 1800s and early 1900s, hundreds of thousands of people (mostly poor) in the southern United States were suffering from the disease known as pellagra. Over 150,000 people died from pellagra in the early 1900s, while others suffered with untreatable symptoms from the disease known as the Four D's: depression, dermatitis, diarrhea, death. For decades, it was unknown what caused pellagra, but many scientists thought it was linked to the corn-rich diet of the south. Dr. Joseph Goldberger, a Hungarian immigrant and epidemiologist, believed that pellagra was a diet-related disease. It was later discovered, after his death, that nicotinic acid (more commonly known as the vitamin 'niacin' or 'vitamin B_3') was lacking in the diets of those suffering from pellagra. Much of the corn consumed in the southern United States was degerminated (processed to remove the germ portion of the corn kernel); the germ portion contains niacin.

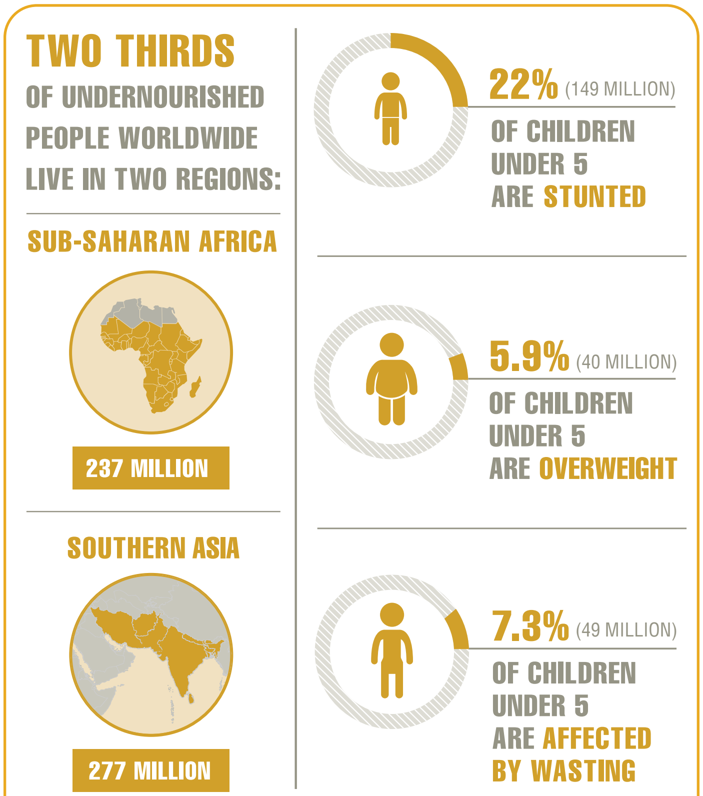
In 1940, the FDA held the "flour hearings," and a team of scientists, doctors, and the Surgeon General worked tirelessly to propose adding thiamin, riboflavin, and niacin to bread. Cornbread and white breads lacking certain nutrients would be "enriched" with a fortified vitamin-rich flour. Enriched (fortified) white bread caused pellagra to virtually disappear overnight.

In February 2018, the World Health Organization (WHO) cited that about 1.9 billion people on earth were estimated to be overweight or obese, whereas almost half a billion people were estimated to be underweight. According to the United Nations, more than 1 in 10 people do not get enough to eat and 1 in 3 people are malnourished. Around 45% of deaths among children under 5 years of age are linked to undernutrition, mostly occurring in low- and middle-income countries. At the same time in these countries, rates of childhood overweight and obesity are rising. Although there is an increase in obesity, many of those people are also undernourished – a condition known as **hidden hunger.**

Women, infants, children, and adolescents are at highest risk of malnutrition. From conception to a child's second birthday, it is important that infants have access to nutrient-dense foods to ensure the best start in life, with long-term benefits.

Malnutrition (WHO definition)
Malnutrition, in all its forms, includes undernutrition (wasting, stunting, underweight), inadequate vitamins or minerals, overweight, obesity, and resulting diet-related noncommunicable diseases.

Hidden Hunger (WHO definition)
Hidden hunger is a lack of vitamins and minerals. Hidden hunger occurs when the quality of food people eat does not meet their nutrient requirements, so the food is deficient in micronutrients such as the vitamins and minerals that they need for their growth and development.



From the United Nations

Poverty can be one of several contributors to malnutrition. Malnourishment increases healthcare costs, reduces productivity, and slows economic growth, perpetuating a cycle of poverty and poor health. Malnutrition impacts every country in the world in some form and fighting malnutrition is one of the biggest global health challenges today. The United Nations is committed to an initiative known as "Zero Hunger by 2030." For an infographic with additional detail about this initiative, see www.fao.org/resources/infographics/infographics-details/en/c/1003923/.

BACKGROUND INFORMATION

Agricultural Methods to Enhance Nutrient Availability

The problem of malnutrition is complex and solving it will require an integrative approach that combines various public health interventions, such as providing oral supplementation, nutrition education, access to nutritious foods, and improving the nutritional composition of food. Various approaches have been used to help optimize nutrient intake for plants, animals, and people, as well as to minimize toxins and anti-nutrients.

Agricultural methods include:

- Selective breeding without molecular biology techniques to assist plant or animal selection
- Selective breeding with molecular biology techniques to support plant or animal selection
- Genetic engineering (GE) tools

Each of these is used to enhance plant nutritional profiles.

Nutrient Enhancement

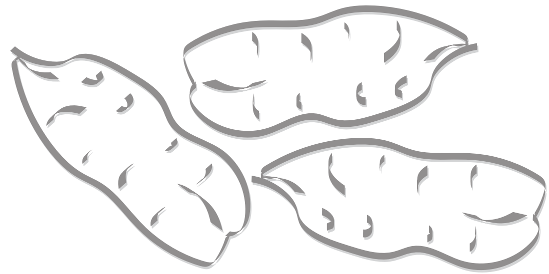
Traditionally, many techniques were employed to enrich the nutrient density of food. Nutritional value that is changed during the processing of food crops (post-harvest) is called **fortification**. Breads that have added riboflavin, thiamin, and niacin are examples of fortification.

Newer technologies, known as **biofortification,** include the use of plant breeding methods (both conventional plant breeding methods and GE tools) to increase the levels of certain key nutrients in foods. Through biofortification, staple food crops, such as rice and cassava, are developed to obtain varieties with higher levels of a single or several nutrients and improved agronomic traits (e.g., high-yield). Biofortification is a way to reach populations where conventional (post-harvest) fortification can be difficult to implement with little or no processing of crops, or for people who may have limited access to commercially fortified products.

Examples of biofortification projects include:

- Iron-biofortification of rice, beans, sweet potato, cassava, and legumes
- Zinc-biofortification of wheat, rice, beans, sweet potato, and corn
- Provitamin A carotenoid-biofortification of rice, sweet potato, maize, and cassava
- Amino acid and protein-biofortification of maize, sorghum, and cassava

To date, most crops with enhanced nutrient profiles have been developed using selective breeding without GE tools.



Biofortification of the Sweet Potato in Uganda

Many people in Uganda are Vitamin A deficient. Vitamin A deficiency (VAD) lowers immunity, impairs vision, and may lead to blindness and even death. In Uganda, 32% of children under 5 years old are estimated to be Vitamin A deficient. Annually, Uganda loses about 145 million dollars to vitamin and mineral deficiencies (World Bank, 2009). To fight against this epidemic, researchers studied the typical Ugandan's diet to determine how to increase their overall intake of Vitamin A.

People of Uganda traditionally eat a white-fleshed sweet potato that lacks Vitamin A. Through conventional selective breeding, the orange-fleshed sweet potato was bred to be rich in Provitamin A carotenoid (beta-carotene), which is a precursor to Vitamin A, as a replacement for the white-fleshed potato in the diets of the people of Uganda. The successful integration of this new crop into Ugandan's diets was the result of key collaboration among scientists, the government, farmers, and the people of Uganda.

Farmers were taught how to grow this new sweet potato variety that was also well-suited for the environment. In addition, technical support was provided for processing, storing, and packaging this crop. The people of Uganda were educated about how this orange-fleshed sweet potato could help to improve their lives. Events like music concerts, community outreach programs, films, and community leader endorsements took place to promote its use. The sweet potato was poised as a delicious and healthier alternative that could be incorporated into many traditional and new dishes.

These efforts all contributed to the success and the bright future of the Vitamin A biofortified sweet potato in Uganda.

BACKGROUND INFORMATION

GE Methods of Nutrient Enhancement

Scientists can employ multiple GE methods to develop new plants with enhanced nutritional content. The genetic tools used to increase nutrient content include:

- Increasing gene expression, by increasing gene copy number or by manipulating gene promoter activity
- Adding genes to bridge gaps in a biosynthetic pathway (e.g., Golden rice that contains beta-carotene, a precursor of Vitamin A) or to create new biosynthetic pathways (e.g., omega-3 canola)
- Promoting the expression of transcription factors to turn on innate but inactive biosynthetic pathways in different plant tissues or at different developmental stages (e.g., anthocyanin in tomatoes).

While few nutrient-enhanced plant varieties are currently available, this may change as many are under development.

It's important to know that plants developed for a specific nutritional purpose may also impact the availability of another nutrient. For example, a crop engineered to produce oil with more of the essential fatty acid, linolenic acid (omega-3 fatty acid), could have less of the essential fatty acid, linoleic acid (omega-6 fatty acid).

Some GE crops are in development with increases in multiple nutrients. Spanish researchers have created an African corn variety with 169 times more beta-carotene, 6 times more vitamin C, and twice as much folate. A GE sorghum variety produced by the Biofortified Sorghum Project for Africa has increased levels of beta-carotene, iron, zinc, and essential amino acids. Crops like these may help reduce malnutrition in underdeveloped countries.

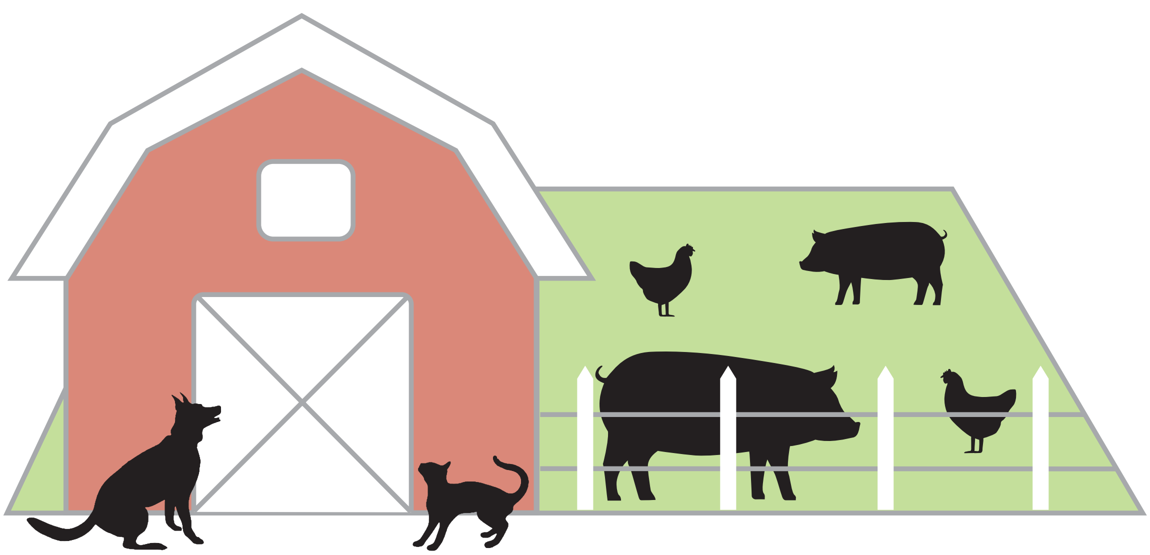
Animal Food

Animals typically eat the same or similar diets their entire lives, and the nutrient requirements for each animal species during each life stage (e.g., pregnancy, lactation, growth, aging) and production conditions (if applicable) have been identified. Although the nutrient requirements (amino acids, fats, oils, carbohydrates, fiber, vitamins, and minerals) are usually defined, animal diets are made from several ingredients including whole grains, oilseeds, by-products of human food production, vitamins, and minerals.

Animal food includes crops cultivated through selective breeding for their nutrient content and can also be supplemented with other ingredients that fortify the food with important amino acids and other essential nutrients needed in animal diets. Periodically, animal nutritionists will review the latest nutrition information and provide guidance on the levels of nutrients that are required to promote good health. Plant breeders try to optimize nutrients in plants consumed by animals using similar approaches to those used to optimize plants for human nutrition.

What's Safe or Unsafe to Eat Differs by Species

Many people enjoy chocolate and cook or season their food with onions and garlic. However, each of these typical human diet items contain substances that can harm cats, dogs, and other animals. If they eat too much of them, it could cause sickness or death.



BACKGROUND INFORMATION

Plant Nutrients - Focus on Nitrogen

Plants get some of their essential nutrients from the air and some from the soil in which they grow. Plants absorb carbon, oxygen, and hydrogen from the air. The three main nutrients they obtain from the soil are nitrogen (N), phosphorus (P), and potassium (K), often referred to as the trio NPK. Some scientists are researching methods to give major crops the ability to "fix" nitrogen from the air into a biochemically usable form. Nitrogen fixation is currently limited to certain microbes, and it is essential to life. Fixed nitrogen is a key ingredient in important biomolecules, including amino acids, which are the building blocks of proteins.

Farmers currently add nitrogen to their crops by applying fertilizer or by planting legumes, which host nitrogen-fixing bacteria in their roots. Altering cereal grain crops to produce their own nitrogen would be an achievement for biotechnology, and this could help solve two big problems: The overuse of fertilizer, which can pollute aquifers or water bodies, and the shortage of fertilizer experienced by small farmers in the developing world.

Varied International Approaches

Internationally, crops developed using GE tools are usually referred to as "genetically modified," GMOs, or bioengineered (BE). As of 2017, 17 million farmers in 24 countries report producing over 469 million acres of "genetically modified" crops. Although many countries are producing crops that include GE plants, many more import GE crops for use in food for humans and animals. Various countries adhere to different policies and legislation regarding current production, import, and export of genetically modified crops. For an overview of GE crops by country, see *ISAAA: 22 Years of Biotech Crops in the World:* **http://www.isaaa.org/resources/infographics/22yearsofbiotechcrops/22%20Years%20of%20Biotech%20Crops%20in%20the%20World.pdf**

Select Nutrient-modified GE Plant Varieties*	
Canola	Laurical™ - more lauric acid
	Phytaseed™ - increases phosphorus availability in animal food
Corn/maize	Mavera™ - increases production of the amino acid lysine
Rice	Golden Rice – contains beta-carotene (provitamin A)
Soybeans	Treus™, Plenish™ - less polyunsaturated fat (linoleic and linolenic acid), more monounsaturated fat (oleic acid)
	Vistive Gold™ - less polyunsaturated fat (linoleic acid), less saturated fat (palmitic acid), more monounsaturated fat (oleic acid)
Pineapple	Rosé – increased lycopene

*Check the ISAAA website for up-to-date regulatory status globally.

Source: **www.isaaa.org/gmapprovaldatabase/commercialtrait/default.asp?TraitTypeID=4&TraitType=Modified%20Product%20Quality%20in%20the%20World.pdf**