

Nutritional Quality of Crops as Affected by Management Practices

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Abstract

The nutritional quality of field and horticultural crops may be influenced by many factors such as inherent soil composition, climate, the crop and its cultivar, cultural and management practices, and postharvest handling and storage. Contradictory results obtained from research on conventional versus organic farming methods regarding crop yields, mineral and vitamin contents are reviewed. Because of the current concerns about food safety and quality and their potential impact on human and animal health, other issues, such as maturity at harvest, postharvest handling and storage, anti-nutritive components as well as chemical residues, are discussed. Some research needs that may ensure the production of safe and nutritious food are also identified.

Introduction

A long-held tenet is that “healthy soils” produce healthy and nutritious food and, in turn, ensure healthy human beings and animals (Albrecht, 1975; Rodale, 1971). During the first half of this century, the relationship between agricultural practices and the nutritional quality of food was widely debated. However, after World War II, public interest in agriculture’s role in human nutrition declined because the increased use of chemical fertilizers and pesticides resulted in an ever increasing surplus of basic food crops. The use of food additives also greatly extended the shelf-life and increased the availability of processed foods. Because of the abundance and availability of foodstuffs and the great diversity of food sources, the relation between soil quality (especially soil management factors) and nutritional quality of food has been largely ignored. However, postharvest handling and storage, which can significantly affect the nutritional quality of fruits and vegetables, have been emphasized.

The USDA’s “Report and Recommendations on Organic Farming” (USDA, 1980) concluded that there was insufficient evidence to show that organically-grown produce was nutritionally superior to produce grown with chemical fertilizers. The lack of scientifically-sound and statistically-valid data from experiments with properly controlled variables was the principal reason for this conclusion. An exception was that marketable produce might contain excessive amounts of pesticide residues and nitrates.

In the past, soil quality has been primarily equated with soil productivity. Today, however, the concept of soil quality has been broadened to include environmental quality, food safety and quality, and human and animal health (Parr et al., 1992). This report examines some environmental, cultural and management practices that may affect the nutritional quality of field crops, fruits and vegetables, and discusses some of the research needs and strategies that may help to ensure the safety and nutritional value of food for the consumer.

Factors Affecting Nutritional Quality

The major factors affecting the nutrient content of field crops, fruits and vegetables are soil factors, climate, the crop and its variety, management practices, and postharvest handling and storage.

Soil Factors

Soils vary greatly in their proportions of sand, silt, clay and organic matter which can significantly affect such properties as pH, water holding capacity, porosity, cation exchange capacity, and mineral composition. Crops such as alfalfa, grasses and blueberries require a specific range in soil pH for optimum growth. The relation between soil pH and macro- and micronutrient solubility determines the availability of soil nutrients; in turn, growth and yield of crops and their ultimate nutrient contents are affected.

Climate

Light intensity, temperature and rainfall interact to affect the nutrient content of plants, and each varies considerably depending on the season and specific growing conditions (Somers and Beeson, 1948). Increases in light intensity can significantly increase the ascorbic acid (Vitamin C) and thiamine (Vitamin B₁) contents of vegetables (Harris, 1975). Moreover, stresses exerted by extremes in temperature and water, and nutrient availability (particularly deficiencies) can markedly affect nutrient uptake and growth of crop plants.

Crop and Variety

Various crops differ in their nutrient requirements; i.e., nitrogen-fixing legumes do not require nitrogen fertilizer while cereals, and many vegetable and fruit crops do. Each crop has its own specific macro- and micronutrient requirements for optimum growth and yield. In addition, the nutrient requirements and final nutrient contents of a particular crop can also vary depending on the cultivar. For example, a carrot variety (Beta III) was recently developed that yields 270 mg kg⁻¹ of beta-carotene, almost three times that of most commercial carrot varieties (Dr. P.W. Simon, Department of Horticulture, University of Wisconsin, Personal Communication). A beta-carotene content of this magnitude could help to alleviate the Vitamin A deficiency that seriously impairs human health in many developing countries. Although the development of exotic cultivars offers great potential for enhancing the nutritional quality of crops, the situation is further complicated by soil, climatic factors and site specific considerations.

Lantz et al. (1958) reported that local growing conditions can affect the protein content of several varieties of dried beans (Table 1). Salunkhe and Desai (1988) found that the ascorbic acid and carotenoid levels of a variety of vegetables grown at six geographic locations varied significantly. Nevertheless, they concluded that “because plant foods are widely distributed from the point of growth, local growing and cultural conditions do not have any impact on the occurrence of specific nutrients in vegetables sold in supermarkets.” This conclusion may not be valid for vegetables that are grown largely in household gardens, or on farms close to local markets.

Table 1. Effect of Cultivar and Location on Percent Protein of Dried Beans (Lantz et al., 1958).

Cultivar	Location			Mean
	Deming (4300ft)	Estancia (6000ft)	State College (4000ft)	
295	20.0	30.8	22.8	24.5
641	20.9	32.1	24.8	25.9
‘Michelite’	23.8	34.4	25.7	28.0
‘Red Mexican’	19.9	29.0	22.5	23.9
2374	19.9	30.9	24.4	25.1
2534	20.0	29.9	26.2	25.4
‘Calico’	19.8	30.1	23.9	24.4
Mean	20.4	30.9	24.3	25.2

Management Practices

After World War II, U.S. agriculture shifted from mixed crop/livestock systems toward specialized cash grain production farming. In recent decades, most livestock have been confined to commercial feedlots. As a result, the use of animal manures and crop rotations to maintain soil tilth and fertility was abandoned on many farms, and large inputs of chemical fertilizers and pesticides were necessary to maintain acceptable crop yields (Power and Follett, 1987). Primary emphasis was placed on the development of crop varieties with maximum yield potential.

Without crop rotations, animal manures, and adequate crop residues, it is virtually impossible to protect soils in monoculture systems from extensive degradation through wind and water erosion, nutrient runoff, and organic matter depletion. Consequently, many of our agricultural soils have

declined in tilth, fertility and productivity (Hornick and Parr, 1987). Moreover, environmentalists and consumers have become increasingly concerned about groundwater pollution by agricultural chemicals, and the effects of those chemicals on food safety and quality. Because of these concerns, there is a growing interest in shifting from high-chemical input systems and monocultures to low-chemical input systems through alternative practices including crop rotations, integrated pest management, and conservation tillage (National Research Council, 1989).

Such changes in agricultural chemical and management practices are likely to affect the crop nutrient content. For example, increased applications of nitrogen fertilizer often increase the yield and protein content of barley, wheat, and rye, but may not increase protein quality (Rendig, 1984). The ratio of essential amino acids (those that the body cannot synthesize) to non-essential amino acids decreased with increased nitrogen application, thereby lowering protein quality. With oats and corn, increased use of nitrogen fertilizer resulted in greater amounts of total protein but the ratio of essential to non-essential amino acids was about the same. These results indicate that changes in nitrogen inputs can affect not only the protein content of some crops but also protein quality.

Maturity, Postharvest Handling and Storage

Variety selection, and postharvest handling and storage have received considerable attention. An important consideration is the maturity of each crop at harvest. A review by Kader (1987) showed that apples and apricots picked green contained no ascorbic acid; however, if they were picked either half ripe or fully ripe, the amount of ascorbic acid increased to approximately 18 and 60 mg per 100 g fresh weight, respectively. Peaches responded similarly to apples, but green mangoes contained 60 mg of ascorbic acid per 100 g fresh weight that decreased to 14 mg when the fruit ripened.

During postharvest handling of crops, temperature and humidity can have major effects. Some nutrients, such as ascorbic acid, are especially heat sensitive. For example, kale kept for 2 days at 21°C under humid conditions lost 60 percent of its ascorbic acid compared with storage at 0°C. Under low humidity, the loss increased to 89 percent (Kader, 1987). Likewise, nutrient losses also occur during storage of crops such as potatoes even at optimum temperature and humidity (Kader, 1987; Knorr and Vogtmann, 1983; Linder, 1985). Potatoes can lose 60 to 70 percent of their ascorbic acid in storage, whereas losses in riboflavin and niacin are minimal even after 240 days in storage (Kader, 1987).

Table 2. Changes in Vitamin Content Caused by Physical Factors (Dietz and Erdman, 1989).

Vitamin	Changes in Vitamin Content	
	Losses Caused By	Increases Caused By
Tocopherol	Oxidation	-
Ascorbic acid	Oxidation	Heat and light
Vitamin A	Oxidation	Heat and light
Carotene	Oxidation	Heat and light
Vitamin D	Oxidation	Heat and light
Thiamin	Oxidation	Alkalinity
Riboflavin	Light	Alkalinity
Pyridoxine	Light	Alkalinity
Vitamin K	Light	Alkalinity
Folic acid	Light and heat	-
Biotin	Alkalinity	-
Pantothenic acid	Alkalinity and acidity	Heat
Niacin	Heat stable but leachable	-

Some physical factors that can lead to changes in specific vitamins are shown in Table 2 (Dietz and Erdman, 1989). Some vitamins, such as ascorbic acid and folic acid, are sensitive to heat and can be

rapidly degraded during transport, storage and processing. Because major nutrient losses can occur in postharvest handling and processing, it is important that crops be consumed or processed immediately after harvest, or transported and stored at optimum temperature and humidity.

Pesticides and Other Crop Contaminants

Some crops, such as legumes, root crops, beans, cruciferous vegetables and cassava, can contain anti-nutritional factors such as protease inhibitors, lectins, goiterogens, and cyanogens. Fortunately, these components are usually destroyed before consumption by moist heat during cooking (House and Welch, 1984; Dietz and Erdman, 1989). Other contaminants, such as mycotoxins and nitrates, can cause severe problems (Clancy, 1986). Aflatoxin (a specific mycotoxin) is a powerful carcinogen that is produced by a fungus (*Aspergillus flavus*) in corn grain, peanuts, and cottonseed when these crops are grown under stress from high temperature and moisture deficit. Nitrates ingested in food and water by infants can cause methemoglobinemia upon conversion to nitrites, and they can be further transformed into carcinogenic nitrosamines.

Consumers are increasingly concerned about the use of chemicals, including pesticides and preservatives, in growing and processing food crops. Some residual pesticides pose greater health risks for certain segments of our population, including the sick, the elderly and the children. For example, children need more food per unit of body weight than adults; therefore, exposure to harmful substances is greater because of both the greater intake and the longer lifetime exposure (Thonney and Bisogni, 1989; National Research Council, 1993).

Organic and Conventional Fertilizers

The fertilizer value of organic soil amendments must also be considered. For example, the average percentage composition of N, P and K in cattle manure is 1.9, 0.6 and 1.4, respectively. The average values of N, P and K for swine manure are 2.8, 1.3 and 1.2, and for poultry manure are 3.8, 1.9 and 1.8. All of these values are subject to considerable variation (Parr and Colacicco, 1987). Similarly, the average N, P, and K contents for such materials as alfalfa hay (2.5, 0.5, 2.1), grain straw (0.6, 0.2, 1.1), soybean meal (7.0, 1.2, 1.5) and bone meal (4.0, 23.0, 0.0) vary with cultural, management and processing factors (Maga, 1983). Therefore, recycling of these materials to soil as biofertilizers and soil conditioners can lead to considerable differences in crop response.

Table 3. Effect of Organic Fertilizer Relative to Chemical Fertilizer on Crop Yield.

Reference	Crop	Organic Treatment Effect¹
Hansen (1981)	potatoes, carrots	0
	beet roots, kale	0
Haworth (1961)	potatoes, cabbage	+
Kansal et al. (1981)	spinach	-
Keipert et al. (1991)	apples, beets, carrots	-
	spinach, leeks, cabbage	-
Lairon et al. (1984)	lettuce	0
Lockeretz et al. (1984)	corn, wheat, soybeans	-
	oats, hay	0
Nilsson (1979)	carrots, leeks	0
	cabbage	-
Peavy and Greig (1972)	spinach	-
Schuphan (1972, 1974)	leafy vegetables	-
Svec et al. (1976)	lettuce, tomato, pepper	0
	peas, onion, potato	0
USDA. (1980)	wheat, corn	-
	oats	0
	soybeans	+

¹0 = no effect; + = positive effect; - = not tested.

Knorr and Vogtmann (1983) showed that crop variety, type of compost, and fertilizer level affected the yield of spinach although there was no predictable pattern between the source of fertilizer and crop variety. A summary of the effect of organic fertilizers on crop yields as compared with chemical fertilizers is reported in Table 3. Because of wide differences in crop varieties, soils, and agroclimatic conditions, caution must be exercised in concluding that one source of fertilizer is superior to another with regard to yield. A good example of how studies of organic vs. chemical fertilizers can be confounded by unequal fertilizer levels, not only between years but also within and between treatments, is shown in Table 4. Obviously, it is impossible to make valid comparisons between organic and chemical sources of N, P, and K in such treatments.

Table 4. Nutrients Applied to Organic and Conventionally Amended Garden Plots, Newark, Delaware (Svec et al., 1976).

Amendments	N	Nutrients Added	
		P ₂ O ₅ (kg/1000 m ²)	K ₂ O
<i>Organic Plot - 1972</i>			
Dairy cattle manure	1.83	1.10	1.83
Cottonseed meal	14.64	6.10	4.15
Blood meal	<u>5.86</u>	<u>0.73</u>	<u>0.28</u>
1972 Total	22.33	7.93	6.26
<i>Organic Plot - 1973</i>			
1972 additions plus:			
Rock phosphate	0	48.82	0
Dairy cattle manure (mid-season)	<u>0.91</u>	<u>0.55</u>	<u>0.92</u>
1973 Total	23.24	57.30	7.18
<i>Conventional Plot - 1972</i>			
5-10-10 fertilizer	12.20	24.41	24.41
<i>Conventional - 1973</i>			
1972 addition plus:			
5-10-10 fertilizer (mid-season)	<u>7.31</u>	<u>14.64</u>	<u>14.64</u>
1973 Total	19.51	39.05	39.05

Other problems with studies that compare the effects of organic and chemical fertilizers include insufficient duration, lack of replication, varietal differences, inadequate design, and differences in materials and methods for calculating yield and nutrient composition (i.e., dry vs. wet weight). Because of the many parameters that must be controlled in comparative studies, it is not surprising that reported yields are confounded. Consequently, contents of minerals, vitamins and other nutrients are also often confounded.

In controlled hydroponic experiments with available nitrogen as the only variable, ascorbic acid (Vitamin C) in kale decreased by more than 50 percent when the nitrogen rate increased from 5 mg liter⁻¹ to 150 mg liter⁻¹ (Hornick and Parr, 1989). Therefore, a possible explanation for some of the discrepancies concerned with the effect of organic matter on Vitamin C content may be related to the level of available soil nitrogen and how it might be affected by mineralization and immobilization processes, and not just to organic or chemical fertilizer components.

The moisture content of the crop at harvest is another parameter that needs to be considered when comparing the effects of organic and chemical fertilizer sources on crop yield. Schuphan (1972) noted that organically-grown crops had a lower moisture content than those grown conventionally. This may have been a factor in the study of Knorr and Vogtmann (1983) who reported that storage losses were lower in organically-grown crops. For example, storage losses for organically-grown potatoes, carrots, turnips and beets were 17.7, 18.0, 15.7 and 29.4 percent lower, respectively, than

for these same conventionally-grown crops. Thus, although the yields at harvest were similar, the lower storage losses resulted in higher after storage yields and starch contents for the organically-grown crops.

The effect of excess nitrogen on the nutritional quality of crops has received considerable study. Excess N can diminish taste and flavor, lower resistance to diseases (rust and downy mildew), lower resistance to insect damage (mites and aphids), and reduce the biological value of plant protein (Schuphan, 1972,1974; Knorr and Vogtmann, 1983; Linder, 1985).

Excess N also can reduce carbohydrate synthesis; the resulting lower content of glucose can affect taste and flavor. Moreover, glucose is required for ascorbic acid synthesis, and the ascorbic acid content decreases in crops as available fertilizer nitrogen increases (Hornick and Parr, 1987).

Suppression of soil-borne plant pathogens by organic amendments, such as animal manure or compost, probably results from the introduction of beneficial microorganisms that are antagonistic to and/or competitive with the indigenous soil microbial population (Lumsden et al., 1982). The often reported increase in resistance to insect damage may be the result of a lower moisture content and resultant thicker cell walls, which would impede penetration by certain insects.

Research Needs

Many factors can affect the nutritional quality of crops both before and after harvest. Table 5 lists factors that can be controlled, such as duration of the experiment, crop and crop cultivar, statistical design, postharvest handling and storage conditions. It also lists those that are difficult to control such as climate, soil type, and disease and insect resistance.

Table 5. Factors Affecting the Nutritional Quality of Crops.

Controllable	Difficult to Control
	<i>Preharvest</i>
Duration	Soil type
Crop	Climate (light, rain, temperature, humidity)
	Disease, insects
	Organic matter (crop and animal residues)
Replication	
Statistical design	Planting date
Sampling (plant part, etc.)	Harvest date
	<i>Postharvest</i>
Storage conditions	
Post-harvest processing	
Taste/sensory evaluation panels	
Nutritional analyses/health aspects/ bioavailability studies	

In many of the studies that compared the effects of organic and chemical fertilizers, certain controllable factors were, in fact, not controlled. Thus, it is almost impossible to make valid and meaningful comparisons. The variable effects of these factors need to be accounted for in any experimental design. The two most important considerations are (1) to evaluate the effect of soil cultural and management practices on the nutritional quality of crops and (2) to assess the effect of these practices on the bioavailability of food nutrients after ingestion by humans and animals. Even if no significant differences are found for the first, we must not assume that there are no differences in the second.

A multi-disciplinary approach is needed to assess the interaction of soil quality and human nutrition. This research should involve soil scientists, plant breeders, and human nutritionists. Such studies should focus on a wide range of growth factors that are important in both plant and animal nutrition, not just a few vitamins and mineral nutrients. Moreover, the analyses should be conducted using the

most current methods and analytical techniques. The possible existence and significance of linkages between soil quality and the health status of humans and animals need to be thoroughly explored using the most sophisticated means available. If improving soil quality could enhance the nutritional quality and bioavailability of foods, such information would find an immediate beneficial application in areas where foods are locally produced and consumed, and in Third World countries where diets are generally non-diverse and mainly comprised of cereal and vegetable crops.

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