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Health Correlates of Nutrients in Soils and Foods

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ABSTRACT

Utilizing food systems to improve nutrition without the need for artificial fortification of food or use of dietary supplements of mineral nutrients is important in ending malnutrition. Malnutrition from deficiencies of mineral elements is reported to be on the rise worldwide, even in the United States. It is estimated that half of the world population suffers from incidences of mineral nutrient deficiencies. These deficiencies limit the physical, intellectual, and mental health activities of the affected people. The deficiencies appear to derive from diminished contents of mineral nutrients in foods of plant (vegetables, fruits) or animal (meats, milk, cheese) origins. With fruits and vegetables, the decline in nutrients is related in part to depletion of nutrients from soils without adequate replenishment with fertilization. Some of the diminished nutrient contents in fruits and vegetables may be related to genetics of new cultivated varieties of produce. Research is needed to develop systems of food crop production that will supply adequate mineral nutrition directly through crop-related foods and from meats and dairy products from livestock and poultry that are provided with adequate mineral nutrition.

Keywords: malnutrition, mental health, mineral nutrition, nutrition and health, nutritive value of foods

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INTRODUCTION

Malnutrition is considered as a primary factor limiting human productivity in modern times (Kataki and Babu 2002). Deficiencies of certain chemical elements, known as mineral nutrients, in diets of humans are a substantial nutritional problem throughout the world (Moore *et al*. 1984; Graham and Welch 2000; Eichholzer 2003; Darnton-Hill *et al.* 2005). These mineral nutrients include elements such as calcium (Ca), magnesium (Mg), phosphorus (P), potassium (K), iron (Fe), iodine (I), zinc (Zn), selenium (Se), and chromium (Cr) among others (Welch 1995, 2002). People with a low intake of calories or with high requirements of micronutrients, as well as people with special food habits or inadequate food choice or handling, are especially at risk of receiving inadequate mineral nutrition (Eichholzer 2003). Correction of Fe and I deficiency in humans is a common topic in chapters in a book on improving food system for human nutrition (Kataki and Babu 2002).The longevity of certain populations in the world has been associated commercially with the ingesting of larger amounts of mineral nutrients than the average person does in North America (Truehope Nutritional Support Ltd. 2001). Even in many countries with adequate food supplies, a rise in incidences in mineral-nutrient deficiencies in humans has been noted (Graham and Welch 2000). Inadequate availability of mineral-nutrient-rich foods is in part a cause of these nutritional deficiencies (Schaetzel and Sankar 2002).

Deficiencies of these nutrients limit the physical and mental capacity of people and may contribute to many physical disorders, such as headaches, heart disease, arthritis, and hypothroidism (Moore *et al.* 1984; Swenson 1996; Simsek *et al.* 1997) as well as mental health conditions such as adverse mood states, bipolar affective disorder, schizophrenia, attention deficit disorder with hyperactivity (ADHD), depression, dementia (Benton and Donohoe 1999; Rayman 2000; Van de Weyer 2006) and learning disabilities (Kaplan *et al.* 2002; Liu *et al*. 2004). Dietary deficiencies are likely to continue into the future if food production and consumption do not deliver sufficient nutrients to sustain healthful lives. The dietary deficiencies are noted with consumption of foods of plant or animal origin and include fruits, vegetables, meats, and dairy products, for which the contents of some mineral nutrients have fallen substantially since the 1930s (Anonymous, Food Magazine 2005, 2006).

The preponderance of fast-food eateries, the ubiquity of highly processed canned and boxed foods with preservatives for long shelf-life, availability of ready or prepared meals, changing dietary habits, and the availability of foods in local markets generally have led to dramatic changes in the quantity and quality of nutrients that people consume (Eisenhauer 2001; Van de Weyer 2006; Hopkins and Thomas 2008; Lasley and Litchfield 2008; Munoz-Plaza *et al.* 2008). For example, dietary intake of sodium (Na) exceeds

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minimum daily requirements, whereas intakes of K, Ca, Mg, and micronutrients are far below recommended standards (Schaetzel and Sankar 2002; Karppanen *et al.* 2005). Bouis (1996) noted that mineral and vitamin deficiencies affect a greater number of people in the world than protein-energy malnutrition and suggested that farmers should grow commonly eaten food staple crops that fortify their seeds with vitamins and essential minerals to obtain a significant, low-cost improvement in human nutrition. The knowledge gained through research about how nutrients in foods affect human health has led to widespread improvements in human health (Combs 1994). Research programs established by the United States Department of Agriculture and State Experiment Stations investigated food and nutrition made the results available to people (Combs 1994). Despite this progress, the science of nutrition is still relatively new, and knowledge is far from complete. Application of new technologies will help to identify individual differences in nutritional requirements among people, to describe nutrient interactions, and to define food constituents needed for healthful diets (Combs 1994). Consumers need research-based information about foods and nutrition, as demand in the market place determines the foods that agriculture and industry produce.

TRENDS IN FOOD COMPOSITION

Research suggests that the mineral nutrient contents of foods are declining with time. Comparing mineral concentrations of fruits and vegetables in 1980 with those of 1930 in the United Kingdom indicated that modern foods were depleted by about 20% (Anonymous, Food Magazine 2005, 2006). Another study also in the United Kingdom reported a general decline in mineral nutrients in forty foods (Mayer 1997). A study in Australia noted declines in nutritional fats, carbohydrates, thiamin, and vitamin A, and in addition, Ca and Fe were of particular concern (Cashel and Greenfield 1995). Mineral nutrients identified as potential deficiencies for many Americans included Ca, Mg, K, and Zn (Moshfegh 2005). Research on the dietary intake of nutrients by subjects in Philadelphia gave results that warranted downward revision in the intakes of Fe, Mg, and vitamins B-6 and B-12 (Guenther *et al.* 1994). Ma *et al*. (2007) concluded that many Americans are not meeting the current recommendations for adequate Ca intake through diet alone or with supplements. Anderson et al. (1992) concluded that Cr contents of grain products, fruits, and vegetables vary widely and depend on Cr introduced in the growing, transport, processing, and fortification of the foods. They noted that even well-balanced diets may contain suboptimal levels of dietary chromium. Some researchers have suggested that changes in cropping systems along with plant breeding and introduction of new crops to improve the nutrient contents of foods and feeds are needed to address the mineral nutrient requirements of humans and livestock (Graham *et al.* 2007; Grusak 2008).

Food production and farming techniques have undergone substantial changes since the 1950s, and through the introduction of new varieties of crops, altered practices in fertilization, conservation of resources, and environmental concerns, these changes may have affected the nutritional values of foods, especially concerning mineral nutrients. Substantial differences occur among plant species and varieties with respect to accumulation of mineral elements so that crops may be selected for their nutrient contents, but these differences can be overwhelmed by environmental factors (Boius 1996; Farnham *et al.* 2000). Generally, in high-yielding crops as is the case with many modern cultivated varieties, carbon assimilation exceeds nutrient accumulation so that the concentration of minerals in foods derived from crops is diluted (Jarrell and Beverly 1981). Enrichment of the atmosphere with carbon dioxide and higher temperatures decrease the concentrations of nutrients in produce through the dilution effect (Fangmeier *et al.* 1999; de la Puente *et al.* 2000; Fangmeier *et al.* 2002), thus potentially lowering the nutritional quality of the food even though the total accumulation of nutrients may be higher because of the elevated yields.

The decline in dietary mineral nutrients has been associated with the depletion mineral nutrients in soils by cropping and with the development of modern varieties of fruits and vegetables that might be inherently lower in nutrient accumulation than older varieties. Increasing crop yields is a major goal of plant breeders. The Green Revolution has doubled or tripled the yields of small grains in developing countries since the 1960s to 1970s (Davis 2009). Yields of vegetable and fruit crops also have increased markedly during this time. Carbon is assimilated into plant dry matter more intensively than minerals are accumulated in high-yielding crops, producing a dilution effect on the mineral concentrations. Davis (2009) notes that the yields of vegetables have increased relatively more than those of fruits (apples, oranges, banana, peach, and others), hence giving a greater relative decline in minerals in vegetables than in fruits. Davis (2009) noted that side-by-side comparisons of low- and high-yielding vegetables and grains showed consistently negative correlations between yield of produce and concentrations of minerals and proteins. To obtain the same amount of mineral nutrition, consumers would have to eat more of the less-concentrated foods than of the more-concentrated foods to obtain the same amounts of nutrition. However, White *et al*. (2009) reported that with potato (*Solanum* spp. L.) a dilution effect on high yields on nutrient concentration was not observed universally and that interactions among mineral elements in the soil and in crops would affect the mineral nutrients in potatoes more than the dilution effect.

More plant nutrients are removed from soils by high-yielding crops than by low-yielding crops; hence, unless nutrients are replenished, soil fertility will be depleted likely leading to diminished nutritional quality of foods. Applications of fertilizers to cropland do not seem to be rising at the same rates as yields of crops are increasing (Havlin *et al.* 2005; United Nations Statistics Division 2007; United States Department of Agriculture ERS 2008). Furthermore, the amounts of principal nutrients, nitrogen, phosphorus, and potassium, applied to crops have effects on the nutritional values of fruits and vegetables. Applications below or above optima for crop production can lead to increases or decreases in vitamin and micronutrients in the produce (Welch 2002). Fertilization directly with micronutrients to increase their concentrations in fruits and vegetables may lead to enrichment of fruits and vegetables with these nutrients that appear to be occurring in diminishing quantities in foods (Welch 2002).

FOOD COMPOSITION AND MENTAL HEALTH

During the last half century, the incidences of mood disorders, learning disabilities, attention-deficit disorders, and non-volitional aggressive behaviors in children have increased. One promising area of research explores the role of nutrients for proper functioning of neurotransmitters for mood modulation, learning disabilities, and aggression inhibition (Kaplan *et al.* 2002; Liu *et al.* 2004; Kaplan and Shannon 2007). In this regard, lithium is a mineral postulated to be essential for mental health and also having lost potency in the soil (Masironi 1979). A clinical trial at the University of Calgary with a 36-ingredient micronutrient supplement (primarily vitamins and minerals) is currently underway to ascertain its efficacy for bipolar disorder, depression, and other mood disorders (Kaplan *et al.* 2001; http://clinicaltrials.gov/ct2/show/NCT00109577). The results suggest that formal clinical trials of broad nutritional supplementation are warranted in children with these psychiatric symptoms and that some cases of bipolar illness may be ameliorated by nutritional supplementation. Rucklidge *et al.* (2010) also reported that a 36-micronutrient formulation of minerals and vitamins gave improvements in mood and quality of life of adults with inattention disorders, hyperactivity, anxiety, and stress.

Although perhaps only indirectly related to mineral nutrition and mental health, Omega 3 fatty acids have proven to be particularly important (Burgess 2000; Richardson 2001, 2003; Haag 2003; Nemets *et al.* 2006) and also having declining concentrations in some plant-derived foods. Omega 3 fatty acids are being evaluated in clinical trials for bipolar disorder and schizophreia (Carlezon *et al.* 2005; http://www.mclean.harvard.edu/research/bipolar/) along with studies of mineral nutritional deficits in mood stability (Popper 2001; Dulcan *et al.* 2002).

VEGETARIAN DIETS

Vegetarian diets are associated with health benefits, which may derive from the dietary fiber and vitamins, antioxidants, and other organic nutrients of fruits and vegetables (Anderson 1990; Cerda 1990; Strohle *et al.* 2006). The nutritional value of fruits and vegetables has been emphasized in dietary recommendations to avoid chronic, degenerative diseases, such as cardiovascular diseases and cancers (Campbell 1990; Ali and Abedullah 2002). Dietary recommendations, therefore, have included increasing the consumption of fruits and vegetables to lessen incidences of these diseases (National Research Council 1989). On the other hand, concerns arise whether vegetarians get enough dietary minerals from a meat-free diet (Barr and Rideout 2004; New 2004). Dietary supplements may be especially necessary for people on vegetarian diets. Fruits and vegetables are relatively poor sources of dietary Ca, but a study showed no difference in bone health among humans who were vegetarians or omnivores. However, bone health and vegetarian diets was called a complex area of investigation (New 2004). Questions also arise concerning if foods suitable for vegetarian consumption contain sufficient iodine (Lightowler and Davis 2002).

PRODUCTION SYSTEMS AND MINERAL NUTRIENTS IN FOODS

The decline in dietary mineral nutrients has been associated with the depletion mineral nutrients in soils by cropping and to the development of modern varieties of fruits and vegetables that might be inherently lower in nutrient concentration or accumulation than older varieties. Soil fertility problems associated with nutrient depletion by crop production are worldwide (Tan *et al.* 2005). Certain geographical areas of the United States and of other countries may have mineral-nutrient-deficient soils that lead to restricted accumulation of nutrients in foods. An evaluation of estimated nutrient removal indicated that in the United States, K and P are being drawn down in soils at an increasing rate every year and that the depletion has occurred for 40 years for K and for nearly 30 years for P (Stewart, 2004). Nutrient mining of soils, removal of more nutrients through crop production than is returned by fertilization, occurs throughout the World (Dobermann *et al.* 1996; Ayoub 1998; Lal and Singh 1998; Nandwa and Bekunda 1998). Elemental depletion of soils must be compensated for by return of nutrients by fertilization in sustainable production of nutrient-sufficient foods (Buol 1995).

Organic production systems

Methods of production may lead to differences in nutrient accumulation. Organically grown fruits and vegetables might differ from conventionally grown produce due to differences in kinds of fertilizers used in the two practices. Low availability of nutrients in organic fertilizers could limit their accumulation in plants. A review by Roe (1998) noted that compost increased nutrient concentrations in soils but not always in plants. Herencia *et al*. (2007) reported few and no consistent differences in nitrogen (N), P, and K concentrations in several vegetables in crops fertilized with composts and crop residues or with synthetic mineral fertilizers. On the other hand, Kirchmann *et al.* (2007) reported that for yields of crops in nutrient-depleted soils in Sweden, organic fertilization with farm manure, slag, rock phosphate, potassium aluminum silicate, and potassium sulfate and use of cover crops was inferior to fertilization with superphosphate, potassium chloride, and manure slurries. Nutrient content was not determined in this research, but one might infer that restrictions in yields were due to limited nutrient availability in soils and accumulation in the crops. On the other hand, high availability of certain nutrients or failure to provide certain elements in chemical fertilizers could lead to nutrient imbalances in foods (Lundegardh and Marensson 2003). For example, Turan and Sevimli (2005) reported that farm manure had a more favorable effect on certain plant constituents (nitrate and oxalic acid) than potassium nitrate. A recently published study (Benbrook *et al.* 2008) reported that organically grown foods derived from plants were superior to those grown conventionally with respect to P, K, nitrates, several antioxidants, and vitamin C. Benbrook (2009) suggested that the high yields achieved through farming systems with high, N fertilizer inputs led to a dilution of nutrient density in vegetables relative to organic systems with low, N inputs. This dilution effect results from larger cell sizes and higher water contents in the systems with high-N inputs.

Regardless of soil conditions, fruits and vegetables, although high in vitamins, are typically low in nutrients such as Zn, Mn, Fe, Se, and Cr (Elless *et al.* 2000). Fruits are naturally low also in nutrients such as Ca, Mg, and K (Drake *et al.* 1974; Johnson *et al.* 1983; Perring and Pearson 1984; Wojcik 2001). At common concentrations of nutrients in foods, people would need to consume large amounts of fruits and vegetables to meet the minimum daily intake of mineral nutrients. Except for K, the fruit-vegetable food group contributes less than 30% of the total dietary intake of mineral nutrients (Levander 1990). About 10% of less of the dietary Na, Ca, Fe, Se, Zn, and molybdenum (Mo) is derived from fruits and vegetables. A decline in mineral content of fruits and vegetables would compound the problem of supplying nutrition through these foods. To counter this problem, several attempts have been made to increase the mineral nutrient content of fruits and vegetables by applying practices such as enrichment of foods with supplements, genetic improvement of crops, or by fertilization of soils.

ENRICHMENT OF FOODS

An effective way of enhancing nutrient intake from normal-sized portions of foods is to enrich the foods with nutrients. Fortification of foods with micronutrients has been suggested, emphasizing Fe, I, and vitamins (Mannar 2002; Ames 2006). Fortification can occur by direct additions of nutrients to foods, such as iodization of salt or additions of micronutrients to bread and flour. Industrial development has produced food supplements for dietary intake of minerals and vitamins (Truehope Nutritional Support Limited 2001). The supplements are suggested to augment the intake of nutrients in diets that may be lacking in sufficient consumption of fruits and vegetables or in cases that the fruits and vegetables and other foods do not contain adequate minerals and vitamins for human nutrition. Several techniques have been used to increase Se intake including adding of Se to foods and fertilizers (Varo *et al*. 1988; Levander 1990). High-selenium wheat grain was included in the diet of steers (*Bos taurus* L.) to achieve selenium-enrichment of the beef (Taylor *et al.* 2008). Selenium-enriched meat had 3.8 times more (1085 vs. 283 ng/g wet weight) Se than meat from steers given a diet with adequate Se without any measurable changes in other nutritional factors associated with meat quality. Caution must be taken when deciding whether to enrich foods with elements, such as Se, because of the toxicity of the elements. The National Institutes of Health noted that certain risks occur with the ingestion of these supplements and using fortified foods. Among these risks was the over-consumption of certain nutrients (NIH 2006). Plants also might be altered by breeding or by fertilization to accumulate nutrients equivalent to those in fortified foods since several mineral nutrients essential for humans also are plant nutrients. Bouis (2007) suggested that biotechnology can help to improve the nutrition and health of consumers in developing countries by increasing the vitamin and mineral content and their bioavailability in staple foods. Genetic improvement has been suggested as a means of enhancing the nutritive value of sorghum and millet feeds for livestock (Zerbini and Thomas 2003). Some research has suggested that transport of nutrients with the flow of water in plants can affect distribution and concentration of elements in edible plant parts (Pomper and Grusak 2004). Hence, improved production practices, such as irrigation, may enhance the minerals in plants.

By way of enrichment of the medium in which plants are grown, plants may be induced to accumulate elements that are valuable to humans as well as to the plants. With hydroponics (Hoagland and Arnon 1950), it is possible to control plant nutrition precisely and to ensure that the plants have adequate nutrition for their growth. But in addition, it is possible to induce plants to accumulate nutrients beyond their needs and into a region of accumulation called *luxury consumption*. In the region of luxury consumption, plants accumulate nutrients without any toxic effects on their growth and development. Luxury consumption may be a means of enriching vegetables with mineral nutrients for human consumption. Furthermore, studies of the accumulation of nutrients by various types and varieties of vegetables or fruits grown in nutrient-enriched media can help to explain whether the declines in nutrient values in foods are the results of limited availability of nutrients in soils or due to changes in plant genetics that limit the capacity of plants to accumulate nutrients.

All reports do not show general downward trends in mineral nutrient concentrations in fruits and vegetables. For example, Davis *et al*. (2004) compared the United States Department of Agriculture data published in 1950 and in 1999 for the nutrient contents in foods from 43 garden crops, mostly vegetables. For 13 nutrients evaluated, six (including Ca, P, and Fe) were reported to decline in these foods, whereas the others showed no statistical trends. The authors (Davis *et al.* 2004) suggested that declines in nutrient contents could be explained by changes in cultivated varieties with tradeoffs between yields and nutrient contents. LeBlanc *et al*. (2005) reported that average or high consumers of food in France had a low probability of health risks due to food consumption with regards to essential or nonessential elements.

CONCLUSIONS

Various research reports suggest that the mineral nutrient contents of foods, including fruits, vegetables, and meats, have declined with time. This decline has been associated with low soil fertility brought about by extracting of nutrients from soil by crop farming and not replenishing the nutrients with fertilization. Also, new varieties of crops appear to have differing nutritional requirements than old varieties and may accumulate lesser amounts of the nutrients or require higher levels of soil fertility to accumulate the same amounts of nutrients as old varieties. Also, the higher yields of modern varieties relative to old varieties can lead to dilution of the nutrients in the produce if accumulation of nutrients does not match yield enhancement. Review of this research indicates a need for further assessments of the concentrations of nutrients in current foods relative to foods of the past. In this assessment, identification of the crop varieties grown today and those grown in the past is needed. Several publications are available for consulting for composition of foods (Paul and Southgate 1978; Heimann 1980; Exler 1983; Haytowitz and Matthews 1984; Ensminger 1986; Haytowitz and Matthews 1986; Dickey and Anderson 1992; Cashel and Greenfield 1995), and the USDA National Nutrient Database for Standard Reference lists current nutrient contents in fresh and prepared foods.

It is important that practices of crop production deliver enough nutrients to sustain health and productive human lives. Methods of increasing the nutrient content of foods must be developed through improved practices in fertilization and with the development and selection of crop varieties that accumulate the nutrients in amounts that are adequate for intake in normal diets of humans.

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