Journal of Food Composition and Analysis 56 (2017) 93–103

Contents lists available at ScienceDirect

Journal of Food Composition and Analysis

journal homepage: www.elsevier.com/locate/jfca

Study Review

Mineral nutrient composition of vegetables, fruits and grains: The context of reports of apparent historical declines

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ARTICLE INFO

Article history:
Received 8 June 2016
Received in revised form 7 October 2016
Accepted 22 November 2016
Available online 25 November 2016

Keywords:
Vegetables
Fruit
Grains
Mineral nutrients
Nutrient composition
Nutrient historical decline
Food analysis
Food composition

ABSTRACT

Reports of apparent historical declines in mineral nutrients of vegetables, fruits and grains, allegedly due to soil mineral depletion by agriculture, triggered this critical review. Comparisons of food composition data published decades apart are not reliable. Over time changes in data sources, crop varieties, geographic origin, ripeness, sample size, sampling methods, laboratory analysis and statistical treatment affect reported nutrient levels. Comparisons with matching archived soil samples show soil mineral content has not declined in locations cultivated intensively with various fertilizer treatments. Contemporaneous analyses of modern versus old crop varieties grown side-by-side, and archived samples, show lower mineral concentrations in varieties bred for higher yields where increased carbohydrate is not accompanied by proportional increases in minerals – a “dilution effect”. Apparent declines, e.g., the extreme case of copper from −34% to −81%, represent small absolute changes: per 100 g dry weight vegetables have 0.11–1.71 mg (1555% natural range of variation), fruit 01–2.06 mg (20,600% range), and grains 0.1–1.4 mg (1400% range); copper composition is strongly subject to the dilution effect. The benefits of increased yield to supply food for expanding populations outweigh small nutrient dilution effects addressed by eating the recommended daily servings of vegetables, fruits and whole grains.

Contents

1. Introduction

Internet articles and popular press frequently state that the mineral nutrient composition of vegetables, fruits and grains has been declining over the past 50 years. These sources may cite, as supporting evidence, scientific literature that compared nutrient data from food composition tables published many years apart, even though the authors of the scientific literature cited often explicitly recognized limitations of their data and analysis. Apparent historical declines in food mineral nutrient content derived from food composition table comparisons have been attributed by popular press authors to a decrease in the levels of micronutrients in the soil due to depletion by intensive agriculture, even when that was not a cause identified in the scientific articles they cite.

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http://dx.doi.org/10.1016/j.jfca.2016.11.012

The objectives of this article are to review and analyze the available scientific evidence for changes in the mineral nutrient composition of vegetables, fruits and grains, and their possible causes, and to assess the significance of validated analytical findings with regard to the nutritional well-being of consumers.

2. Background: public perception based on the popular press

In the popular press and on the internet, a very frequently repeated quotation is, "A Kushi Institute analysis of nutrient data from 1975 to 1997 found that average calcium levels in 12 fresh vegetables dropped 27%; iron levels 37%." The Kushi Institute (http://www.kushiinstitute.org/) is an organization that describes itself as having a "macrobiotic approach to health and healing" that promotes healing foods and lifestyle changes for health improvement. The numbers come from an article written by Jack (1998), a health writer associated with the Kushi Institute, comparing U.S. Department of Agriculture (USDA) food composition tables from 1997 versus 1975, to identify changes in the levels of nutrients in fresh foods. The quotation comes from an open letter to the U.S. Secretary of Agriculture, Dan Glickman, written by *Organic Gardening* Senior Editor Cheryl Long (Long, 1999). Thus, while the original source of information, USDA food composition tables, is authoritative, a direct comparison of the values does not take into consideration differences in crop varieties or methods of nutrient analysis, and provides no information on potential causes of reported differences. The Kushi Institute report was apparently not subjected to scientific peer-review.

Thomas (2000) prepared a report on historical nutrient content changes that was published by Mineral Resources International (UK) Ltd., an ingredient supplier and manufacturer of liquid and tablet nutritional supplements using minerals and trace minerals from Utah's Great Salt Lake. Thomas compared data on 27 varieties of vegetables, 17 varieties of fruit, 10 cuts of meat and some milk and cheese products, using nutrient composition tables from the U.K.'s *McCance and Widdowson's The Composition of Foods* first edition published in 1940 compared with the data for the same foods from the fifth edition published in 1991. He concluded that the results demonstrated that there has been a significant loss of mineral macronutrients and trace elements in these foods over that period of time, with the most dramatic losses relating to the copper (Cu) present in vegetables between 1940 and 1991 (76%) and zinc (Zn) between 1978 and 1991 (59%). He suggested that the results of the study can be linked to recent dietary, environmental and disease trends, including contamination of vegetables, fruits and meat with pesticides, hormones, heavy metals, antibiotics and food additives, trace mineral depletion of the soil, excessive use of nitrogen-phosphorus-potassium (N-P-K) fertilizers, changes in crop varieties, loss of micro flora/fauna within the soil, etc. However, he provided no supporting evidence for these factors as explanations for the differences he observed.

Another widely cited report is an *Earth Talk* column written and edited by Scheer and Moss (2011) for *E – The Environmental Magazine*, which is published on the *Scientific American* website. This is often cited as an article published in the journal *Scientific American*, which is not correct. The column, written as a response to a reader's question about nutritional differences in a carrot eaten today from one eaten in 1970, states categorically that fruits and vegetables grown decades ago were much richer in vitamins and minerals than the varieties available today and that "the main culprit in this disturbing trend is soil depletion: Modern intensive agricultural methods have stripped increasing amounts of nutrients from the soil in which the food we eat grows. Sadly, each successive generation of fast-growing, pest-resistant carrot is truly less good for you than the one before." They cite as supporting evidence the Kushi Institute study and two scientific studies (Davis et al., 2004; Mayer, 1997; both discussed in detail below) despite the fact that none of these studies present any evidence that a change in soil mineral nutrient content is an important causative factor.

3. Scientific evidence from food composition table comparisons

One of the first and most frequently cited peer-reviewed scientific papers on apparent historical changes in the mineral content of fruits and vegetables was published by Mayer in 1997. She compared the results of analyses for 8 mineral nutrients: sodium (Na), K, calcium (Ca), magnesium (Mg), P, iron (Fe), Cu, and Zn, in 20 fruits and 20 vegetables, raw, peeled, from two U.K. *Chemical Composition of Foods* reports dating from 1960 (reporting results from analyses done in 1936) and 1991. The foods were not dried or rehydrated and dry pulses were excluded. She reported finding statistically significant reductions in the levels of Ca (−19%, $P = 0.014$), Mg (−35%, $P < 0.001$), Cu (−81%, $P < 0.001$), and Na (−43%, $P = 0.013$) in vegetables and Mg (−11%, $P = 0.016$), Fe (−32%, $P = 0.002$), Cu (−36%, $P = 0.006$) and K (−20%, $P < 0.001$) in fruits. The only mineral nutrient that showed no significant difference over the ~50 year period was P. Mayer noted that potential sources of deviation included possible differences in the methods of sampling; methods of analysis (although older methods were characterized as taking longer but no less accurate); mixed sources of data for the 1991 edition; greater use of imported and "out of season" produce; different storage and ripening systems; and changes in varieties bred for higher yield, response to modern methods of agriculture, post-harvest handling qualities and cosmetic appeal. She noted that water content increased significantly and dry matter content decreased significantly in fruits between the new and old data sets but did not attempt to correct for moisture content. Mayer stated that "in principle, modern agriculture could be reducing the mineral content of fruits and vegetables" but noted that evidence was needed to find out if this was significant. She did not demonstrate a cause-and-effect relationship between her findings and soil mineral content, nor did she present evidence that any of the nutrient content changes were of importance to human nutrition. She identified these as areas for future research.

Lyne and Barak (2000) reviewed the evidence for depleted soils causing a reduction in the mineral content of food crops as suggested by comparison of USDA food composition data. They found that for three major cations: Ca^{2+}, Mg^{2+}, and K^{+} of selected fresh produce crops, there was no real loss in the balance of mineral nutrition in food crops. They stated that widespread use of soil testing and fertilizers as part of the strategy for the increasing yields of modern agriculture argues strongly against the notion of widespread soil depletion of mineral nutrients. They concluded that although it may be hypothesized that a decline in soil quality has led to an apparent decline in food nutrition, more controlled studies are needed to factor out the many variables associated with the food composition tables and this type of analysis.

Bringing more statistical rigour to the food composition table comparison approach, Davis et al. (2004) compared USDA Food Composition Table data from 1950 and 1999, for water, energy, protein, fat, carbohydrate, ash, Ca, P, Fe, vitamin A, thiamin, riboflavin, niacin, and ascorbic acid in 39 vegetables, 3 melons and strawberries. Fibre was excluded due to the change of analysis from "crude" to "dietary" fibre. Dry matter content was calculated by difference with the water content, and 1950 nutrient content values were adjusted to the same moisture level as the 1999 data by multiplying them by the ratio of dry matter in 1999 samples over dry matter in 1950 samples.

Davis et al. (2004) found that changes for individual foods could not be assessed reliably due to large uncertainties in the mineral nutrient content data but grouped together, statistically significant decreases from 1950 to 1999 were seen for Ca (−16%, $P = 0.014$), P (−9%, $P = 0.002$), and Fe (−15%, $P = 0.005$). Sources of uncertainties the authors identified in the results included sampling (geographic including imported versus locally grown crops, seasonal, and portion of outer leaf or stem considered edible); cultivars tested; analytical methods (e.g., early values for Fe tended to be high according to Davis et al., 2004); environment (climate, distribution methods, location of production, etc.); and the source of data, since the 1950 values were derived mostly from the literature rather than nationally representative composites. The authors stated that despite the popular interpretation that mineral nutrient decreases in produce may be due to mineral deficiencies in soil, they found that about 28% of the ratios (R-values) of the 1999/1950 values of nutrient content for each food commodity exceeded 1 (i.e., nutrient content increased), which was difficult to reconcile with a broad mineral-depletion hypothesis. They concluded that factors other than soil mineral content seemed to have primary control of food mineral content.

Exceptions to this are iodine (I) and selenium (Se). These two minerals are accumulated by plants from the soil in significant concentrations despite the fact that they are not essential mineral nutrients for plants. At low levels Se has been shown to be a "beneficial element" for plants; observations of positive effects of low levels of I on plant growth have been reported but a scientific basis for I as a plant micronutrient has not yet been elucidated (Smoleń et al., 2014).

A possible explanation for lower mineral nutrient concentrations put forward by Davis et al. (2004) was related to changes in cultivars selected for yield, rapid growth, pest resistance, herbivory resistance, and number versus size of seeds. They suggested that these changes may result in differences between cultivars in their ability to extract soil minerals, transport them within the plant, and to synthesize proteins, vitamins and other nutrients. However, they recognized that these differences are unpredictable in magnitude. Thus, historical nutrient content differences were attributed to a combination of several factors. Cultivar selection for yield may have changed acquisition and synthesis of nutrients and enhanced the dry matter or carbohydrate (starch, sugar and/or fibre) and water fractions of vegetables without proportionate increases in other nutrients (i.e., a "dilution effect"). On the other hand, a large and unpredictable degree of genetic variability caused other cultivars to have increased levels of nutrients. The authors noted that plants cannot grow or be viable commercial vegetable and fruit crops without acquiring the minerals and synthesizing their own needed broad range of nutrients. They reminded readers that currently available vegetables and fruits remain broadly nutrient-dense foods so a diet rich in whole foods including vegetables, fruits, whole grains, nuts and beans will still provide the nutrients we need for good health.

White and Broadley (2005) compared food composition data from both the U.K. (1930s vs. 1980s) and the U.S. (1930s vs. 2004) to further test the hypothesis that the mineral composition of vegetables and fruits or nuts shows historical variation. They found that, when grouped, in the U.K. there were significant decreases since the 1930s in the average concentrations of Cu (−73%, $P < 0.001$), Mg (−19%, $P = 0.023$), and Na (−50%, $P = 0.004$) in dry matter of vegetables and Cu (−34%, $P = 0.007$), Fe (−15%, $P = 0.036$) and K (−10%, $P = 0.026$) in dry matter of fruits. From the U.S. data they calculated significant declines in the average concentrations of Ca (−37%, $P < 0.001$), Cu (−40%, $P = 0.028$) and Fe (−75%, $P < 0.001$) in vegetables and Cu (−36%, $P = 0.010$), Fe (−72%, $P < 0.001$) and K (−13%, $P = 0.043$) in fruits. However, they too concluded that there was insufficient data to assess mineral content changes in any one crop, that there is considerable genetically-based variation in mineral nutrient content between horticultural crop genotypes, and that the observed changes in mineral composition are unlikely to be significant in overall dietary terms.

4. Contemporaneous laboratory analyses compared to historical mineral nutrient data

In a report prepared by scientists from Food Standards Australia New Zealand (FSANZ) in response to news media attention to the Mayer (1997) article, Cunningham et al. (2002) compared P, Na, Ca, Mg, Fe and Zn levels measured in 44 types of Australian fruits and vegetables purchased in Melbourne, Australia, in 2000 or 2001, with results of analyses conducted between 1981 and 1985 for the same items of produce purchased in Sydney, Australia. They found no significant or consistent differences in their mineral content over time. Explicit limitations that they noted included that the samples were collected in different locations, sometimes at different times of the year, possibly at different stages of ripeness, in many cases were different varieties, and older analyses were conducted using a less sensitive analytical technique. They concluded that any minor changes from year to year in mineral levels in these foods would be very unlikely to be of dietary significance.

Ekholm et al. (2007) conducted laboratory analyses of the content of the mineral nutrients Ca, K, Mg, P, cobalt (Co), Cu, Fe, manganese (Mn), nickel (Ni), Se, and Zn, as well as the toxic minerals aluminum (Al), cadmium (Cd), and lead (Pb) from samples of 18 vegetable products, 16 fruits or berries and the cereals wheat, rye, barley and oats from Finland. The results were compared with laboratory mineral nutrient analysis results from the same foods (28 pairs for comparison) published 30 years previously. Their findings were that of the major mineral elements Ca, K, Mg, and P, only the content of K had decreased significantly ($P = 0.038$), mainly in cereals and only moderately in other food crops. However, the content of several of the trace minerals decreased significantly on a weight per dry matter basis: Mn ($P = 0.050$), Zn ($P < 0.001$), Cu ($P = 0.048$), and Ni ($P < 0.001$), and the levels of the toxic minerals: Al ($P < 0.001$), Pb ($P = 0.043$), and Cd ($P = 0.009$). The levels of Se increased ($P = 0.001$) due to increased use of Se as a mineral nutrient in agricultural fertilizers. They attributed the changes in part to new cultivars but recognized that one of the limitations in this study was that the data from the 1970s came from foodstuffs almost completely produced in Finland whereas for the current data many of the foodstuffs were imported.

Bruggraber et al. (2012) and Bruggraber et al. (2013) compared results of current laboratory analyses with U.K. food composition table data obtained from analyses conducted in the 1930s and 1980s, to evaluate any historical changes in the Fe content of vegetables, fruits, and cereal products. They found remarkably little historical difference in Fe content of vegetables, legumes and pulses. Only fruit showed a small but statistically significant decrease of −0.35 mg/100 g (95% CI −0.68 to −0.01) in Fe from the 1930s to the 1980s. There was insufficient published data to allow for comparison of cereal products. Davis (2013), in a Letter to the Editor commenting on the study by Bruggraber et al., noted that the observed differences in Fe content are only "apparent" for several reasons. Bruggraber et al. depended on historical data from different laboratories in different eras. They had large uncertainties due to inadequate numbers of samples to cope with large natural variations among samples of the same food – the median Coefficient of Variation for Fe was 53% in the analysis by Davis et al. (2004) of 43 U.S. vegetables and fruits. Also, Davis (2013) noted that the statistical analysis by Bruggraber et al. was based on means and parametric Confidence Intervals but the distributions of changes have large deviations from normality due to probable outliers, skewing and kurtosis.

Avoiding the potential pitfalls of depending on historical analytical data, Fan et al. (2008a, 2008b) conducted laboratory mineral nutrient analyses of wheat grains and soil samples archived over the last 160 years by the Broadbalk Wheat Experiment, established in 1843 at Rothamsted, U.K., and run continuously ever since. They found that the grain concentrations of Zn, Fe, Cu and Mg remained stable between 1845 and mid 1960s but since then significant decreases were seen in Zn ($P = 0.004$ to <0.001), Cu ($P = 0.021$ to <0.001) and Mg ($P = 0.030$ to $=0.004$), which coincided with the introduction of semi-dwarf, high-yielding cultivars. With regard to the hypothesis that soil nutrient levels are a causative factor, they found that the mineral concentrations in the archived soil samples either increased or remained stable. Reasons for this included inputs of Mg from inorganic fertilizer, Zn and Cu from farm yard manure, and Zn also from atmospheric deposition. The observed decreases in wheat grain mineral content were independent of whether the crop received no fertilizers, inorganic fertilizers or organic manure. Multiple regression analyses showed that the two highly significant factors associated with the downward trend in grain mineral concentration were increasing yield and harvest index (i.e., the weight of the harvested product, such as grain, as a percentage of the total plant weight of the crop, which for wheat was measured as the aboveground biomass due to the difficulty of obtaining the root biomass).

Fan et al. (2008b) noted that the Se concentration of the grain had a much larger range and was significantly higher ($P < 0.001$) in unfertilized plots compared to inorganic fertilizer or manure treated plots and higher in the unfertilized plots in periods before 1920 or after 1970 than during 1920–1970. These temporal and fertilizer-related patterns of Se decrease in the grain were influenced mainly by sulfur (S) inputs from fertilizers and atmospheric deposition of S, which increased sulfate antagonism of selenium uptake, plus a small dilution effect. For these reasons, despite the observed long-term trend (not statistically significant) of an increase in soil Se concentration, primarily due to atmospheric Se deposition, the grain Se content did not increase.

Thus, the findings of Fan et al. from the Broadbalk Wheat Experiment are conclusive with regard to the lack of significant historical decreases in soil mineral levels in the fields they studied and that verified declines in mineral nutrient concentrations in wheat grain were associated with varieties having an increased grain yield. Nevertheless, it is still worthwhile exploring what role other potential causative factors could play in “apparent” historical mineral nutrient declines in vegetables and fruits.

5. Field trials to test hypotheses regarding historical mineral nutrient changes

McGrath (1985) used field experiments to look at the “dilution effect” of increased yields on the mineral nutrient concentrations in grain of winter wheat. He noted that concentrations of P, K, sulfur (S), Ca and Mg varied twofold ($n = 238$); Fe, Zn and Cu varied threefold ($n = 236$); and Mn varied by a factor of 5 ($n = 236$). While the potential for decreases was predictable, e.g., for Zn and Fe which move slowly from the soil into plant roots and thus might not meet the demand of a rapidly-growing crop, a decrease in these minerals with increased yield was not found in these analyses. There were small, statistically significant ($P < 0.01$) varietal differences but they were not large enough to be of agricultural importance; the overall changes in levels in crops with increased yields were positive, except for Mn which did not change.

Farnham et al. (2000) examined variations in Ca and Mg concentrations in a USDA collection of 19 inbred and 27 commercial F_1 hybrids of broccoli grown side-by-side. Broccoli was chosen because it is a good vegetable source of Ca and Mg, and the bioavailability of Ca from broccoli is comparable to that from milk. Levels varied for Ca (1.99–4.35 mg/g dry weight) and Mg (1.94–3.74 mg/g dry weight) among the hybrids within the same growth year due to genetic differences—concentrations were significantly negatively correlated ($P < 0.05$) with broccoli head weight due to greater density, not size. With the inbred lines, the concentration of Mg, but not of Ca, was negatively correlated ($P < 0.05$) with head density. These mineral nutrient content differences correlated with head density are examples of a dilution effect. However, there was also a significant ($P < 0.05$) environmental effect on both Ca and Mg concentrations when comparing two different growing seasons (1996 and 1997). Environmental and genotype-by-environment components of variance for Ca concentration were equal and both were ten times greater than the genotypic component of variance, while for Mg the environmental, genotypic and genotype-by-environment components of variance were of a similar magnitude.

Garvin et al. (2006) also used two replicated field trials rather than published data to examine historical shifts in mineral micronutrient concentration (Fe, Zn, Cu and Se) in 14 different varieties of U.S. hard red winter wheat from production eras ranging from 1873 to the late 1990s. They found significant effects on micronutrient content of cultivation location (Fe, Cu, P and Zn with $P < 0.001$, Se was not significantly different) and significant differences between the genotypes ($P < 0.001$), whose genetic profiles differ due to more than a century of crop development. When the data was organized by release date and yield, Zn content was seen to have decreased significantly with both increasing yield and more recent variety release date at both locations ($P < 0.0001$ and $P < 0.05$); Fe content decreased significantly with increasing yield and more recent variety release date at one location ($P < 0.05$); and Se content decreased significantly with more recent release date at one location ($P < 0.01$). With regard to Cu content, it was lower in grain from one site compared to the other ($P < 0.001$) but there was no correlation with variety release date.

Murphy et al. (2008) used a randomized complete block design nursery to grow 56 historical spring wheat cultivars widely grown in the Pacific Northwest region of the U.S.A. from 1842 to 1965, and 7 modern spring wheat cultivars widely grown in Washington State in 2003. Thirty-seven cultivars were in the soft white wheat market class, 20 were hard red, four were hard white and two were soft red. There were three replicates of each cultivar in one growing season and four replicates of each the following year. Yield and concentrations of Ca, Cu, Fe, Mg, Mn, P, Se and Zn were measured. They found that the modern cultivars had higher yields than the historical cultivars ($P < 0.0001$). The historical cultivars had significantly higher grain mineral concentrations than the modern cultivars: Cu ($P < 0.001$), Fe ($P < 0.01$), Mg ($P < 0.001$), Mn ($P < 0.05$), P ($P < 0.001$), Se ($P < 0.05$) and Zn ($P < 0.001$), the exception being Ca for which the decline in modern cultivars was not statistically significant ($P = 0.07$). There were highly significant variations in the concentrations of each mineral between cultivars ($P < 0.0001$) and a significant genotype-by-year interaction for each mineral as well, although statistical analyses showed that most of the variation was due to genotype rather than year. Overall yield was negatively correlated with mineral concentration for Ca ($P < 0.001$), Cu ($P < 0.001$), Mg ($P < 0.001$), Mn ($P < 0.01$), P ($P < 0.001$) and Se ($P < 0.001$), but not significantly for Fe and Zn. These results can be compared to those of Fan et al. (2008a, 2008b) described above, who reported that levels of Cu, Mg, Fe and Zn were steady in cultivars with release years from 1845 to the mid-1960s and then declined significantly in more modern semi-dwarf cultivars with high yields. Murphy et al. postulated that the lack of a negative correlation between yield and concentrations of

Fe and Zn in their analyses may be because the content of these two mineral nutrients is influenced by the high protein gene *Gpc-B1* which may be subject to positive selection pressure for higher yield where protein content is a consideration. Regressions of mineral concentrations on year of cultivar release, separated into market classes, showed significant decreases among soft white cultivars for all minerals except Ca and Mg. However, among hard red cultivars, only Zn decreased with release date whereas Mg increased slightly over time. All other mineral nutrients remained stable among the hard red cultivars released over the past 120 years. Murphy et al. suggested that the decline in concentrations of most minerals in soft wheat might be due to selection pressure for lower ash content, since high ash content in flour gives a darker colour to finished products which is undesirable with regard to product quality. However, they noted that generally the correlations were weak and exceptions existed for high yielding cultivars with moderately high levels of certain minerals, such as P, Fe, Mg, Mn and Se, indicating that there is genetic potential for development of cultivars with high mineral nutrient levels, particularly for Cu, Zn and Mn.

Ficco et al. (2009) used side-by-side cultivation in two locations and two growing seasons to study mineral nutrient (Ca, K, Mg, Mn, Na, Cu, Fe, and Zn) and phytate levels in Italian durum wheat cultivars. They studied 10 old genotypes released between 1900 and 1973, 58 cultivars released after 1974 that carried semi-dwarfing reduced height *Rht* genes, and 17 advanced breeding lines with high yield potential. They noticed a direct soil content effect on levels of Na and K in the grain, and at one site a higher soil level but lower grain level of Mn. Of the two genotypes with the highest grain Fe content, one was a modern genotype and one an old genotype; for Cu the modern genotypes had a higher content. For inorganic P, Cu, Fe, Na and Zn, the modern genotypes had the widest ranges. No clear trends for historical declines in mineral nutrient composition were observed comparing modern genotypes and advanced breeding lines with old genotypes. Their results suggested a significant dilution effect only for Mg and Zn (both $P < 0.001$) and not for Fe.

Rosanoff (2013) combined analytically determined Mg food content change results such as those of Fan et al. (2008a), Murphy et al. (2008) and Ficco et al. (2009), with a comparison of the Mg content listings in food composition tables of the U.K., USDA, and Health Canada from different publication dates, to conclude that a historical decrease in the Mg content of grains, fruits and vegetables has occurred. From these data sources she derived estimates that grain Mg concentrations have dropped by 7 to 25% and vegetable Mg concentrations have dropped by 15 to 35%. She associated her calculations of food Mg content and food supply data from the USDA with rates of cardiovascular disease (CVD) mortality data from the U.S. NIH. Rosanoff concluded that the results suggested a causal relationship between CVD mortality peaking in the U.S. in 1968 when Mg in the U.S. food supply reached its nadir and then gradually declining as food Mg supply rose in the years up to the present. She recognized that the decline in CVD mortality can be explained mostly by medical treatments and medications, increased exercise and decreased smoking. However, she drew a parallel between the U.S. trend and the rise of rates of CVD mortality, obesity, metabolic syndrome and non-communicable diseases in societies transitioning from traditional diets to modern processed food diets. Rosanoff's main conclusion was that rising global mortality from CVD may be due to lower dietary intakes of Mg (and other nutrients) caused by declining crop content, which she attributed primarily to the change to high-yield varieties, and also to food processing losses. While the Institute of Medicine (1997) has recognized that Mg is a required cofactor for over 300 enzyme systems and that Mg depletion is linked to CVD, neuromuscular diseases, diabetes mellitus, and renal wasting syndromes, Rosanoff's use of data from food composition tables published in different years as supporting evidence for a historical decline in food Mg content is not valid. The linking of CVD mortality rates to postulated historical declines in the Mg content of foods is perhaps oversimplified.

6. Analysis and discussion

Davis (2009) provided a summary and reanalysis of the scientific evidence available up to the time of writing regarding apparent historical decreases in fruit and vegetable nutrient composition and its potential causes. This reanalysis involved calculating the ratios (R) and distribution-independent 95% Confidence Intervals of the nutrient content between new/old varieties of the food using the nonparametric approach of testing the null hypothesis that ratios of group medians equaled 1. Davis preferred a nonparametric approach that provides more conservative results over the statistical approach used in previous studies. Calculating group geometric means and especially the use of a *t*-test (the statistical approach used in the articles by Mayer, 1997; and by White and Broadley, 2005) was determined to be insufficient to account for the skew of mineral nutrient analysis data, which were shown to deviate significantly from a normal distribution (Davis et al., 2004; Davis, 2006). Of the 33 median R values Davis (2009) recalculated, only 11 (33%) of them indicated a statistically significant ($P < 0.05$) apparent nutrient content decline (i.e., $R < 1$). No statistically significant increases in mineral nutrient content (i.e., $R > 1$) were observed. Among the statistically significant ratios (R), the most pronounced apparent declines in mineral nutrients were seen in vegetables. They ranged from approximately 80% for Cu (questionably large but strongly subject to the dilution effect) to approximately 17% for Ca. The decline in Na appeared to be about 40% and the decline in Mg appeared to be about 23%. A statistically significant decline in Fe in vegetables was seen only in U.S. data for a larger group of vegetables (Davis, 2009; Fig. 6). For the content of P in vegetables, the ratio of medians showed a small but statistically significant apparent decline in U.S. data for a large group of vegetables (Davis, 2009; Fig. 3) but no significant change in U.K. data for mixed crops including vegetables, fruits and nuts (Davis, 2009; Fig. 6). In fruits, apparent declines in the median mineral nutrient content were relatively small and not statistically significant ($P > 0.05$, Davis, 2009; Figs. 2 and 5).

Food composition tables and databases, such as Health Canada's *Canadian Nutrient File* (2015a), the U.S. Department of Agriculture's *National Nutrient Database for Standard Reference, Release 28* (SR28) (2015), Public Health England's *Composition of Foods Integrated Dataset* (2015), the FSANZ *Nutrient Tables for Use in Australia* (2015), and the Food and Agriculture Organization (FAO) of the United Nations *International Network of Food Data Systems Food Composition Databases* (2015), provide the foundations for the development of educational programmes on choosing healthy diets that help consumers to make informed choices with regard to the nutritional quality of foods. These databases also provide the basis for assessing population nutrient intake in combination with food intake surveys. However, comparison of historical food composition tables is not a reliable way to determine changes in nutrient composition of foods over time. Their data represent snapshots of nutrient content for foods available on the market at a particular time. There are changes in the genetic varieties of crops on the market over time, large ranges of variation in content of different nutrients from variety to variety of the same crop, and differences in geographic origin, season, degree of ripeness, sample sizes, sampling methods, analytical methods, statistical methods, etc.

With regard to analytical methods, the levels of minerals for most foods in SR28 (USDA, 2016a) were determined by AOAC

Official Methods of Analysis, such as inductively coupled plasma – emission spectrophotometry (AOAC 984.27) for Ca, Fe, Mg, P, Na, K, Zn, Cu and Mn, a method that was the subject of Final Action consideration by AOAC in 1986. Preparation involves digesting the test samples in $HNO_3/HClO_4$ (a wet oxidation process). For some records in SR28, minerals except for P were determined by an atomic absorption method (AOAC 985.35, Revised First Action 1997) for which samples are prepared by dry ashing in a muffle furnace at 525 °C; determination of P in these cases was by a colorimetric method (AOAC 2.019, 2.095 and 7.098, published in AOAC (1980) but involving a method dating from 1957) with sample preparation by wet ashing. This colorimetric method was originally developed for determination of total P in fertilizers; it is listed as AOAC 957.02 in the current Official Methods database (AOAC International, 2016) and the latest revision (in 1998) for colorimetric determination of total P in foods is AOAC 995.11. Additional details on the mineral nutrient analytical methods used by the USDA are available from the SR28 *Documentation and User Guide* (USDA, 2016a).

Much of the food mineral nutrient values in the *Canadian Nutrient File* are derived from the SR database (Health Canada, 2015b) so the data was obtained mostly through AOAC Official Methods for atomic absorption (AOAC 985.35) or ICP-ES (AOAC 984.27). One exception is for data from the Canadian Sampling and Nutrient Analysis Program, which were obtained by an inductively coupled plasma/mass spectrometry (ICP-MS) method based on EPA 3051A (U.S. EPA, 2007). With regard to sample preparation, EPA 3051A uses microwave assisted (instead of conventionally heated) digestion with HNO_3 or a combination of HNO_3 and HCl.

As Mayer (1997) noted, the analytical methods used for the U.K. *Composition of Foods* database similarly have evolved and there is no clear conclusion on the extent to which that has influenced reported differences in mineral nutrient composition. The current seventh edition of the *Composition of Foods* database includes data for many foods analyzed in surveys carried out since the publication of the sixth edition in 2002 and updates where necessary from industry sources, other food composition datasets, and the scientific literature. In the case of carry-over of previous values, they were reviewed by members of the project team to ensure they are still representative of foods currently consumed or else calculations were done to update values. Editions prior to the sixth included data for foods both with and without inedible material or material that may be discarded as inedible by some consumers but in the seventh edition all nutrient values apply to the edible portion as specified in the food name, with edible conversion factors provided in an appendix. Thus, the data reflect changes in food preparation methods, advances in analytical methods, analytical variation, natural ranges of nutrient composition variation, and new varieties of plant foods (Roe et al., 2015).

Attributing different values of mineral nutrient levels in a given food to actual changes in the vegetable, fruit or grain composition over time, when the data are coming from different editions or sources of food composition databases, is inherently a flawed approach since official methods for the analysis of the mineral nutrient content of food have changed over time as the science advances. Some of the very early wet chemistry methods that would have been used in old publications include the 1928 titrimetric method for Al and Fe in plants (AOAC 928.03), 1935 colorimetric method for P in fruits (AOAC 935.45), and 1937 colorimetric method for Fe in plants (AOAC 937.03). Later improvements to these methods such as the 1970 spectrophotometric molybdovanadate method for P in fruits (AOAC 970.39), 1970 gravimetric quinolone molybdate method for P in fruits (AOAC 970.40), and dry ashing/sodium molybdate modifications to the colorimetric measurement of P in method AOAC 995.11 (Pulliainen and Wallin, 1994, 1996) allowed for the ongoing use of less expensive but still reliable methods with less toxic reagents. However, the application of modern chemical analytical instrumentation to determine the composition of mineral nutrients in plant-derived foods started with such methods as the 1975 atomic absorption spectrophotometric method AOAC 975.03 for Ca, Cu, Fe, Mg, Mn, K and Zn in plants, a 1980 direct reading spectrographic method AOAC 980.03 for metals in plants, the 1984 ICP-ES method mentioned above, a 1999 variant on the atomic absorption method (AOAC 999.11) for Pb, Cd, Cu, Fe and Zn in foods, and in 2015 an ICP-MS method AOAC 2015.06 for minerals and trace elements in infant formula and adult/pediatric nutritional formula was published (AOAC International, 2016).

The FDA has also published its own *Elemental Analysis Manual for Food and Related Products* with methods such as ICP-Atomic Emission Spectrometry with microwave assisted digestion (U.S. FDA, 2010) for the determination of 22 nutritive and toxic minerals in foods and an ICP-MS method with microwave assisted digestion (U.S. FDA, 2015) for Cr, Mn, Ni, Cu, Zn, As, Se, Mo, Cd, Hg and Pb levels in foods.

It is important to keep in mind that not all of the data in the food composition databases comes from laboratories using official methods of analysis; in part they are derived from articles in the peer-reviewed scientific literature for which researchers used alternate methods. Some of the more recent developments for plant-derived food mineral nutrient analysis include Neutron Activation Analysis, which does not involve chemical preparation techniques (e.g., Baidoo et al., 2014), visual-near-infrared spectroscopy, to a lesser extent mid-infrared spectroscopy and ultraviolet spectroscopy, chlorophyll a fluorescence, X-ray fluorescence, and laser-induced breakdown spectroscopy (Mir-Marqués et al., 2016; van Maarschalkerweerd and Husted, 2015; Schmitt et al., 2014).

Castanheira et al. (2016) have published European Food Information Resource (EuroFIR) guidelines for the assessment of methods of analysis and proficiency testing with regard to the quality of data to be entered into food composition databases. They note that for some nutrients values from different food composition tables are not comparable mainly due to differences in analytical procedures. Prioritized nutrients for methodological guidance include the minerals and trace elements: Ca, Cu, I, Fe, Mg, Mn, P, K, Se, and Na. They recommended the use of only AOAC, European Committee for Standardization (CEN) and International Organization for Standardization (ISO) methods of analysis for minerals and trace elements. The methods considered appropriate were grouped into ICP-MS for trace elements (Se, I, Zn, Mn), ICP-Optical Emission Spectrometry (OES is also known as atomic emission spectrometry) for minerals present in higher quantities in foods (Fe, K, Na, P, Cu, Ca, Mn), atomic absorption spectrometry (AAS has similar performance to ICP-OES, which is more expensive but has largely replaced AAS), and graphite furnace atomic absorption spectroscopy for Se, although that has largely been replaced by ICP-MS.

Regarding methods of sample preparation, Castanheira et al. (2016) note that extraction or destruction of organic matter before measurement of minerals and trace elements is generally required but this is a slow process and large sources of contamination can occur. Currently, food organic matrix destruction/removal or extraction is conducted through dry ash, wet digestion or pressure digestion procedures which are available at CEN and AOAC. However, each food matrix may require a different strategy and optimization for complex matrices to separate inorganic from organic components.

The laboratory mineral nutrient analyses of wheat grain varieties and soil samples archived over the last 160 years by the Broadbalk Wheat Experiment (Fan et al., 2008a, 2008b), completed with identical sample preparation and analytical methods, have helped to demonstrate that historical declines in mineral nutrient content of food crops can be real but that these changes are correlated with increased yield and harvest index, not soil mineral content. This was borne out by other comparisons of historical food composition data (grouped into vegetables, fruit or grains rather than single food comparisons, and adjusted for moisture content) with mineral nutrient analyses from side-by-side plantings of low- and high-yield cultivars, and fertilization studies. These studies have all demonstrated consistent negative correlations between yield and concentrations of mineral nutrients. In fruits, vegetables and grains, usually 80% to 90% of the dry weight yield is carbohydrate so when breeders select for high yield they may be selecting mostly for an increase in carbohydrate with no assurance that other nutrients will increase proportionately.

The Organisation for Economic Co-operation and Development (OECD), an organisation of 34 countries whose mission is to promote policies that will improve the economic and social well-being of people around the world, publishes international Consensus Documents on compositional considerations for new varieties of crops. At the time of writing, for evaluating the safety of novel foods and feeds there are OECD consensus documents on 18 plant and 2 mushroom crops. These documents are authoritative sources of information on the natural range of macro- and micro-nutrient content in staple food crops, providing necessary contextual information for assessing whether a new variety of a crop, grown in various locations and conditions, is likely to be as nutritious, more, or less nutritious than conventional varieties of the same crop.

For example, regarding bread wheat, the consensus (OECD, 2003) is that “the average mineral content of a given wheat grain varies significantly from one part of the world to another. This appears to be a function of a number of factors, including the wheat variety, the growing and soil conditions, and fertilizer application. The mineral composition of wheat has more to do with environmental conditions, rather than varietal characteristics.” Davis et al. (1984), whose work is cited in OECD (2003), determined the mean and range of Ca, Mg, P, K, Cu, Fe, Mn, and Zn content, and also chromium (Cr) and Se, in statistically valid numbers of samples of wheat of the following classes (each of which has multiple varieties; 231 varieties in total were analyzed, from 49 growing locations): hard red winter, hard red spring, soft red winter, durum, soft white winter, soft white spring, hard white winter and hard white spring.

Results from Davis et al. (1984) and other authors for selected grains, vegetables and fruits are presented in Table 1 to illustrate how widely mineral nutrient content varies among samples and varieties of a single crop species.

Results of studies of the natural range of content of mineral nutrients in food crops, such as those shown in Table 1, support the findings of Davis et al. (2004), Mayer (1997) and White and Broadley (2005) and others that due to the often very large ranges and uncertainties in the nutrient content data for any single crop, historical declines in mineral nutrient content can only be demonstrated when foods are grouped, e.g., as vegetables, fruit, or grains.

Across groups of foods (typically 20–45 food commodities), nutrient content ranges were also very large, as might be expected. For example, across the 43 garden crops studied by Davis et al. (2004), adjusted for moisture differences to compare mineral nutrient composition per 100 g of the edible portion, the 1999 USDA Food Composition Data set indicated that Ca ranged from 2 to 190 mg (9500%) and Fe from 0.07–3.3 mg (4714%). White and Broadley’s (2005) data from the 2002 U.K. and 2004 USDA sources gave ranges of Cu in vegetables, per 100 g dry weight, of 0.11–1.71 mg (1555%) (excluding mushrooms at 4.23 mg), and ranges of Cu in fruit of 0.01–2.06 mg (20600%).

Taking into consideration the multiple caveats described above regarding food composition table data, which are just a “snapshot” of only a few samples from diverse sources, these natural ranges of mineral nutrient content values help to place reports of apparent historical decline in context. The content of each of the major mineral nutrients shown in Table 1 (Ca, K, Mg, P) comprises 5% or

Table 1
Ranges of mineral nutrient content in examples of grains, vegetables and fruits.

Crop	Ca Range[a] (%)	K Range[a] (%)	Mg Range[a] (%)	P Range[a] (%)	Cu Range[a] (%)	Fe Range[a] (%)	Mn Range[a] (%)	Zn Range[a] (%)
Wheat[1] *n* = 404 (231 var.)	8–80 (1000%)	280–730 (261%)	20–220 (1100%)	250–910 (364%)	0.1–1.4 (1400%)	1.6–16.3 (1019%)	1.0–9.0 (900%)	1.5–10.2 (680%)
Rice, brown[2][b]	10–60 (600%)	70–320 (457%)	20–170 (850%)	200–500 (250%)	0.1–0.7 (700%)	0.2–6.0 (3000%)	0.2–4.2 (2100%)	0.7–3.3 (471%)
Maize, sweet[3] [b]	8.3–69 (831%)	900–1560 (173%)	106–281 (265%)	320–625 (195%)	0.08–0.25 (313%)	1.6–3.1 (194%)	n/a	1.9–6.25 (329%)
Barley[4] [b]	40–70 (175%)	300–590 (197%)	90–150 (167%)	230–420 (183%)	n/a	n/a	n/a	n/a
Common bean[5] [b]	9–425 (4722%)	1300–2490 (191%)	100–326 (326%)	230–842 (366%)	<0.04–1.4 (>3500%)	3.14–12.07 (384%)	0.0009–2.63 (292,222%)	<1.89–6.24 (>330%)
Soy bean[6] [b]	120–320 (267%)	1800–2320 (129%)	220–310 (141%)	500–940 (188%)	0.11–1.98 (1800%)	6.0–20.0 (333%)	<2.75–5.9 (>215%)	1.09–6.77 (621%)
Sweet potato, raw peeled[7] [b]	79.0–147.4 (187%)	724.0–1454 (201%)	73.7–87.6 (119%)	135.7–179.2 (132%)	0.5–0.7 (140%)	2.1–6.4 (305%)	1.3–2.6 (200%)	0.6–1.2 (200%)
Broccoli[8] [b]	170–510 (300%)	n/a	160–370 (231%)	n/a	n/a	n/a	n/a	n/a
Tomato, red ripe raw[9] [b]	145.2–181.8 (125%)	3600–4833 (134%)	116.7–206.9 (177%)	379.3–500.0 (132%)	0.67–1.07 (160%)	4.91–8.33 (170%)	1.83–2.07 (113%)	1.50–3.09 (206%)
Papaya, ripe[10] [b]	57.93–285.9 (494%)	1238–2309 (187%)	89.53–229.6 (256%)	44.76–146.8 (328%)	0.12–0.83 (692%)	0.9–14.81 (1646%)	0.081–0.24 (296%)	0.39–2.80 (718%)

Data sources: [1] Davis et al. (1984); [2] Organisation for Economic Cooperation and Development OECD (2016); [3] OECD (2002); [4] OECD (2004); [5] OECD (2015); [6] OECD (2012); [7] OECD (2010a); [8] Farnham et al. (2000); [9] OECD (2008); [10] OECD (2010b).

[a] Range units are mg/100 g dry weight; percent as maximum/minimum × 100%; n/a: not available.

[b] *n* values are not available from OECD consensus document tables since they are compilations of published data.

less of the total dry weight of 100 g; the content of each of the trace mineral nutrients shown in Table 1 (Cu, Fe, Mn, Zn), comprises 0.02% or less of the total dry weight of 100 g. Therefore, a change in a small value for the mineral nutrient content may appear large when expressed as a percentage, as indicated by the very large percentages of natural variation. However, the statistically significant percentages of apparent historical decreases in mineral nutrient content reported in the literature are all well within the broad ranges of natural variation shown in Table 1, whether looking at changes within a single food such as Zn, Cu and Fe in wheat, or across groups of foods such as Cu or Ca in vegetables and fruit.

To provide further context to the mineral nutrient content data provided above and the dietary significance of apparent or real historical declines, it is important to consider how much of these mineral nutrients we need for good health and how well intakes are meeting those needs. The following are some of the mineral nutrient Recommended Dietary Allowance (RDA) or Adequate Intake (AI, indicated below where the value is not an RDA) levels sufficient to meet the nutrient requirements of nearly all healthy adult individuals, which were established by the Institute of Medicine (Ross et al., 2011): Ca from 1000 to 1300 mg/d, P from 700 to 1250 mg/d, K from 4700 to 5100 mg/d (AI), Mg from 310 to 420 mg/d, Cu from 0.9–1.3 mg/d, Fe from 8 to 27 mg/d, Mn from 1.8–2.6 mg/d (AI) and Zn from 8 to 13 mg/d.

Note that Table 1 provides mineral nutrient content per 100 g dry weight to avoid the confounding variable of moisture content when comparing vegetables, fruit and grains. Food composition tables and databases such as those provided by Health Canada, the USDA, Public Health England, FSANZ and FAO provide nutrient content per 100 g fresh weight of the edible portion of the food, or per serving of a particular volume or weight, raw or prepared in various ways. By referring to food composition tables and guidance on recommended daily servings of the various food groups such as the Health Canada (2011) *Eating Well with Canada's Food Guide*, the USDA (2016b) *MyPlate*, or the U.K. National Health Service (2015) *The eatwell plate*, it is clear that vegetables, fruit and whole grains continue to be important dietary sources of mineral nutrients.

To consider the question of adequacy of mineral nutrient dietary intake, Health Canada (2014) recently analyzed nutrient intake data from the 2004 *Canadian Community Health Survey* (Health Canada and Statistics Canada, 2009) to identify those mineral nutrients for which there are inadequate intakes in a significant proportion of the Canadian population. The Institute of Medicine's Estimated Average Requirement (EAR) is the average daily nutrient intake level estimated to meet the requirements of half of the healthy individuals in a group. A shortfall nutrient is defined as a nutrient for which more than 10% of intake values fall below the EAR. The following mineral nutrients: Ca, P, Mg and Zn, were identified as shortfall nutrients among Canadian consumers. Among U.S. consumers, Ca, Mg and K were identified as shortfall nutrients (USDA and USDHHS, 2015).

There is no biomarker or clinical evidence to suggest that there are public health issues related to inadequate intake of P, Zn, or Mg (Health Canada, 2014). Less than 20% of Canadians have K intakes above the AI but since there is no sensitive biochemical indicator of potassium nutritional status, it was not possible to consider biomarker data to inform the prevalence of potassium deficiency. Nevertheless, given the probable low prevalence of adequate intakes and the high prevalence of hypertension in the general population K is a nutrient of high public health concern in Canada (Health Canada, 2014), as in the U.S.

In the U.S., Fe has been identified as a shortfall nutrient for adolescent and premenopausal females (USDA and USDHHS, 2015). Similarly, according to Health Canada (2014), intake data from the 2004 *Canadian Community Health Survey* suggests that there is a low prevalence (<3%) of inadequate intake of Fe for most age/sex groups in Canada, except for females aged 14 to 50 (12% to 18%). Based on data from the *Canadian Health Measures Survey*, Health Canada (2014) noted that the overall prevalence of anemia was low (3%) based on haemoglobin concentrations. However, depleted iron stores were detected among females 12–19 years (13%), while those 20–49 years of age showed lower iron sufficiency, indicating a higher risk of iron-deficiency anemia among both age groups. For these reasons, iron is still a nutrient of public health concern in Canada as well as in the U.S.

For those mineral nutrients for which we have evidence of inadequate dietary intakes, a key conclusion of the reviews by Health Canada (2014) and the USDA and USDHHS (2015) was that the shortfalls can be explained by the large proportion of consumers who do not consume the minimum recommended daily servings of fruits, vegetables, and dairy products; it is not due to a decline in the level of the nutrients in these foods. All vegetables, fruits, beans and peas, unsalted nuts and seeds, whole grains, seafood, eggs, fat-free and low-fat dairy products, and lean meats and poultry—when prepared with little or no added solid fats, sugars, refined starches, and sodium—are nutrient-dense foods (USDHHS and USDA, 2015).

Another factor to consider in evaluating apparent historical declines in mineral nutrient content of crops and a putative association with soil mineral levels is that plants require both macromineral and trace elements for growth and development, although certain minerals such as Se and I required by humans do not appear to be essential for plants (Smoleń et al., 2014). Therefore, if soils were truly deficient the plant would not grow well, resulting in stunted growth, low yields, susceptibility to disease, and malformed produce, so the farmer would not have a crop to sell. To prevent these problems, modern agriculture uses fertilizers. Artificial fertilizers may contain not only the major mineral nutrients N, P, K and S, but also some of the other major nutrients that plants need such as Ca and Mg and some trace minerals, depending on the soil type and crop needs. Organic fertilizers such as composted animal manure and "green manure" crops that are ploughed back into the soil are naturally even more complex in their mineral nutrient composition. While the field trial studies cited above showed that crop mineral nutrient levels obviously can vary with soil mineral levels, none of the field or contemporaneous analysis studies found any scientific evidence that there are significant soil mineral losses leading to vegetable, fruit or grain mineral nutrient content decreases without causing an unhealthy crop that could not be brought to market.

The dilution effect of increased crop yield or harvest index without a proportional increase in mineral nutrient content, resulting in a lower mineral nutrient concentration on a dry weight basis, has been well documented in several vegetable and grain crops. There are technologies available to counter the decline that has been seen due to efforts to breed crops with higher yields. To provide an affordable alternative to existing nutrition interventions and a sustainable solution to inadequate intakes of mineral nutrients from foods, especially in developing countries, "biofortified" varieties of crops such as rice, wheat, barley, maize, pearl millet, beans, peanuts, chickpeas, cassava and guava are being developed that provide consumers with enhanced levels of Fe, Zn, Cu, P, Mg, Ca, Mn, Mo, and Se (and enhanced vitamin content too). Biofortification methods include agricultural practices such as mineral fertilization, addition of soil microorganisms such as mycorrhizal fungi and nitrogen-fixing bacteria, intercropping of dicot with grass crops, and both conventional and transgenic crop breeding methods (De Steur et al., 2015; Hefferon, 2015; de Souza et al., 2013; Dwivedi et al., 2012; Bouis et al., 2011; Zuo and Zhang, 2009; Cockell, 2007; Bouis, 2003; Graham et al., 1999).

7. Conclusions

As with many widespread beliefs, there is a grain of truth to the notion that the mineral nutrient content of certain crops has declined but the story of what has been seen and the importance of these changes are quite different from the popular narrative. Separating the wheat from the chaff when it comes to causes for apparent historical declines in nutrient content can be challenging.

Comparing government food composition table data from different publication years is not a valid approach and the results obtained from these comparisons are misleading as to the nature and degree of changes in the mineral nutrient content of foods over time.

Contemporaneous analysis of different varieties of the same crop grown side-by-side or of archived samples of grain have confirmed that some modern varieties of vegetables and grains are lower in some nutrients than older varieties due to a dilution effect of increased yield by accumulation of carbohydrate (starch, sugar and/or fibre) without a proportional increase in certain other nutrients. However, well-conducted comparisons have shown that consistent trends of decrease in content of certain nutrients are mostly seen only when crops are lumped into broad groups of vegetables, fruits, and grains. Statistical significance is lost when trying to see historical changes by comparing varieties of a single crop due to a high degree of variability. Some modern cultivars have higher concentrations of selected nutrients than older cultivars while other cultivars may have lower concentrations of selected nutrients. The ranges of values for mineral nutrient content may extend over two orders of magnitude or more.

Fruits, vegetables and grains are important dietary sources of mineral nutrients, so if apparent historical declines in their concentrations were real and substantial across a significant proportion of our foods that could have significant implications for the adequacy of our mineral nutrient dietary intake. However, the scientific evidence has shown that while percentage changes in nutrient content may appear to be very dramatic, such as an apparent decline in vegetables' content of Cu by as much as 81%, in fact these large percentage changes represent small absolute changes that are all well within the range of natural variation in mineral nutrient content both within a single food and within the groups of foods reviewed in the literature. To follow through on the extreme case of copper with reported apparent historical declines ranging from −34% to −81%, the context is that per 100 g dry weight, vegetables have 0.11–1.71 mg of copper (a natural range of variation of 1555%), fruit 0.01–2.06 mg (20,600% range), and grains 0.1–1.4 mg (1400% range) so even a change of 81% is well within the natural range of variation, and copper composition has been reported to be strongly subject to the dilution effect. The study authors who found statistically significant decreases in the content of particular mineral nutrients per dry weight of fruits, vegetables, or grains all agreed that these changes were not likely to have any significant impact on the nutritional health of consumers, a fact glossed over in some popular press reports citing these studies. The benefits from increased yield of crops in addressing world hunger are significant. Biofortification is an approach being used in crop development to help address specific nutrient deficiencies especially in developing countries.

As indicated in consumer nutrition guidance from Health Canada, the USDA and USDHHS, the U.K. National Health Service and other agencies, a diet rich in vegetables, fruits and whole grains, which continue to be nutrient-dense foods, will still provide all of the nutrients we need for good dietary health. Thus, the small estimated declines in content of certain mineral nutrients that have been observed in high-yielding crops can be addressed easily by consuming the recommended number of servings per day of vegetables, fruit and whole grains.

Rather than being used to try to find historical changes in the nutrient composition of vegetables, fruits and grains, food composition tables and databases, such as those provided by Health Canada, the USDA, Public Health England, FSANZ and FAO, are more appropriately used by consumers, dieticians and other health care practitioners to support people in making healthy food choices.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Acknowledgements

I would like to thank my Food Directorate, Health Canada colleagues: Josephine Deeks of the Nutrition Research Division, Nora Lee of the Nutrition Regulations and Standards Division, and Lynne Underhill of the Premarket Assessment Division in the Bureau of Nutritional Sciences, and Lidia Loukine of the Biostatistics and Modelling Division in the Bureau of Food Surveillance and Science Integration, for their insightful comments and suggestions during the preparation of this article.

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