



Minerals in plant food: effect of agricultural practices and role in human health. A review

M.C. Martínez-Ballesta, R. Dominguez-Perles, D.A. Moreno, B. Muries, C. Alcaraz-López, E. Bastías, C. García-Viguera, M. Carvajal

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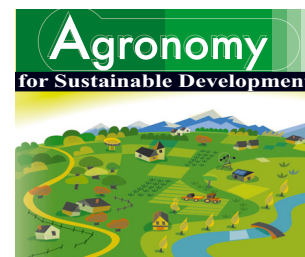
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Review article

Minerals in plant food: effect of agricultural practices and role in human health. A review

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Abstract – Interest in nutrient absorption and accumulation is derived from the need to increase crop productivity by better nutrition and also to improve the nutritional quality of plants as foods and feeds. This review focuses on contrasting data on the importance for human health of food mineral nutrients (Ca, Mg, K, Na and P) and also the trace elements considered essential or beneficial for human health (Cr, Co, Cu, Fe, Mn, Mo, Ni, Se and Zn). In addition, environmental stresses such as salinity, drought, extreme temperatures and light conditions that affect mineral content were revised in the light that the effect of these factors depends on the species or cultivar, and the specific plant organ, as well as the intensity and duration of the stress. Differences between inorganic and organic fertilisation practices on the mineral levels were also analysed to evaluate the influence of external factors on the quality of plant-based foods.

environmental stress / human health / mineral fertilisation / mineral nutrition

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1. INTRODUCTION

One of the most important challenges for agriculture, besides enhancing food production, is to provide almost all the essential minerals and organic nutrients to humans for maintenance of health and proper organ function. Humans need more than 22 mineral elements; some of them are required in large amounts, but others, such as Fe, Zn, Cu, I and Se, are required in trace amounts because higher concentrations can be harmful (Welch and Graham et al., 2004; Grusak and Cakmak, 2005). Although vegetables constitute the main source of minerals in the human diet, crops do not always contain sufficient amounts of these essential nutrients to meet dietary requirements (Welch et al., 1997). Elements that might enhance growth or that have a function in some plants (not in all plants) are referred to as beneficial elements. Concerning mineral nutrients, deficiencies, including those of Ca, Zn, Se, Fe and I, are almost certainly impairing the health and productivity of a large number of people in the developing world, especially poor women, infants and children (Graham et al., 2001). However, an excessive intake of minerals may also have a deleterious effect on the systemic physiology, that has led researchers in the last few years to acquire accurate data on the minimum requirements and toxic dosages of the minerals present in food. The level of minerals in vegetables depends on a number of factors including genetic properties of the crop species, climatic conditions, soil characteristics and the degree of maturity of the plant at the moment of harvesting.

Consideration of the environmental consequences and soil fertility practices are an essential component of the research in plant nutrition. Thus, some plant nutrients, such as potassium and sodium, are involved in plant responses to salt and water stress. Also, recommendations for amounts and application of fertilisers are continually modified to optimise the quality of the food production (Fig. 1).

2. MINERALS IN FOODS OF PLANT ORIGIN: THEIR ROLE IN HUMAN HEALTH

Before attempting to modify the nutritional components in plants destined for human foods, careful consideration must be made in selection of minerals, their efficacy, and whether low

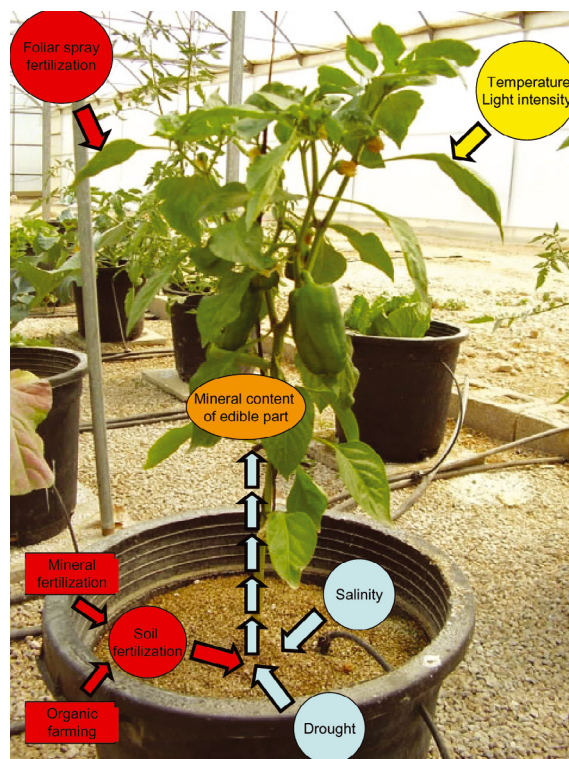


Figure 1. Agricultural practices and environmental stresses affecting mineral composition in vegetables and fruits.

or high dietary intake could have unintended negative health consequences. For selected mineral targets, the clinical and epidemiological evidence clearly plays a significant role in maintenance of optimal health, and they are limited in the diet worldwide (Lachance, 1998). In the following, we summarise the effect that essential or beneficial mineral nutrients have on human health.

2.1. Calcium

The concentration of calcium (Ca) in foods of plant origin shows a wide range of variation. The lower values belong to apples (*Malus domestica*), green pepper (*Capsicum*

annuum) and potatoes (*Solanum tuberosum*) (< 8.7 mg/100 g) and higher values are present in broccoli (*Brassica oleracea* L. var.italica) (100 mg/100 g) and spinach (*Spinacia oleracea*) (600 mg/100 g). Data on the mineral content of foods are important and should be considered when recommending the daily intake of minerals, as the Recommended Daily Allowance (RDA) for these nutrients is set out in the wide range of 800–1300 mg/day (<http://www.anyvitamins.com/rda.htm>). Calcium is an essential mineral for human health, participating in the biological functions of several tissues (musculoskeletal, nervous and cardiac system, bones and teeth, and parathyroid gland). In addition, Ca may act as a cofactor in enzyme reactions (fatty acid oxidation, mitochondrial carrier for ATP, etc.) and it is involved in the maintenance of the mineral homeostasis and physiological performance in general (Theobald, 2005; Huskisson et al., 2007; Morgan, 2008; Williams, 2008). Recent reports showed the unequivocal role of Ca as a second messenger (Morgan, 2008). With respect to disease prevention, Ca intake moderately reduces the risk of colon cancer (Pele et al., 2007; Peters et al., 2004). An increase in Ca intake during pregnancy is recommended to prevent risk of pre-eclampsia (Peters et al., 2004). Several studies have shown an association between suboptimal Ca intake and osteoporosis, hypercholesterolemia and high blood pressure (Unal et al., 2007). Although Ca levels undergo homeostatic controls to avoid an excessive accumulation in blood or tissues, there are a number of conditions that result in an excess of Ca within the body because of a failure in the control mechanisms: hypercalcaemia may occur as a result of either increased mobilisation of Ca from bone, or increased tubular reabsorption or decreased glomerular filtration in the kidneys, and less frequently, as the result of an increase in the dietary intake (Theobald, 2005).

2.2. Magnesium

Magnesium (Mg) has a strong presence in vegetable foods and also shows a critical role in the maintenance of human health through the diet. Vegetables and fruits contain, in general, Mg^{2+} in the range of 5.5–191 mg/100 g fresh weight; and the recommended daily intake is 200–400 mg (<http://www.anyvitamins.com/rda.htm>). This essential mineral acts as a Ca antagonist on vascular smooth muscle tone and on post-receptor insulin signalling. It has also been related to energy metabolism, release of neurotransmitters and endothelial cell functions (Bo and Pisu, 2008). In addition, Mg participates with muscle and nerve excitability, as a cofactor of up to 300 enzymes (Huskisson et al., 2007). Magnesium deficiency is related to ageing and age-related disorders, mainly as a consequence of deficient intake in the diet (Durlach et al., 1998; Killilea and Maier, 2008). Recent findings showed that an increase in the intake of this mineral helps to protect people from the incidence of chronic diseases such as diabetes, metabolic syndrome, hypertension and several cardiovascular conditions (Bo and Pisu, 2008), where a low-Mg diet may contribute to insulin resistance, especially when this deficiency is combined with a high-fructose diet. Moreover, reduced Mg in-

take is linked to inflammatory response as a result of modulation of the intracellular-Ca concentration (Ahokas et al., 2005; Rayssiguier et al., 2006). Magnesium toxic effects are not frequent, the most common side effects of an excessive intake of this mineral being headache, nausea, hypotension and unspecific bone and abdominal pain (Guerrero-Romero and Rodríguez-Morán, 2005).

2.3. Potassium

Foods of plant origin have potassium (K) contents of 20 to 730 mg/100 g fresh weight, although some plants such as 'Idaho' potatoes (*S. tuberosum*), banana (*Musa* spp.) and avocado (*Persea americana*) may all present high K contents (> 700 mg/100 g fresh weight). Seeds and nuts are rich in K, showing values significantly higher than those mentioned above, up to 2240 mg/100 g. The recommended intake for this mineral is 3500 mg per day (<http://www.anyvitamins.com/rda.htm>). Potassium plays a role in the maintenance of the balance of the physical fluid system and assisting nerve functions through its role in the transmittance of nerve impulses. It is also related to heart activity muscle contraction (Rosenthal and Gilly, 2003; Schwarz and Bauer, 2004; Ko et al., 2008; Lambert et al., 2008; Sobotka et al., 2008). However, K requirements are also dependent on the physiological or pathological moment. A deficiency may result in fatigue, cramping legs, muscle weakness, slow reflexes, acne, dry skin, mood changes and irregular heartbeat. Moreover, a reduced level of K produces alkalosis, which makes the kidney less able to retain this mineral. Excessive K can be toxic systemically when associated with hyperkalemia in a catabolic state accompanied by oliguria (secondary to kidney failure) (Sobotka et al., 2008).

2.4. Sodium

Raw vegetables and fruit juices contain relatively low levels of sodium (Na) in the range of 2.28 to 94.0 mg/100 g and from 0.04 to 277 mg/100 g, respectively (Szefer and Grembecka, 2007). The role of Na in human physiology is related to the maintenance of the balance of physiological fluids (blood pressure, kidney function, nerve and muscle functions) (Sobotka et al., 2008; Hall, 2003; Hall et al., 1999; French and Zamponi, 2005). The recommended daily intake for Na is 2400 mg (<http://www.anyvitamins.com/rda.htm>). A deficiency is rare, but it can happen in cases of diarrhoea, vomiting or excessive sweating, and a shortage may lead to nausea, dizziness, poor concentration and muscle weakness, etc. (Smith et al., 2000; Soupart and Decaux, 1996). Excessive Na may be due to an increase in absorption or a secondary condition to kidney alteration, causing high blood pressure and neurological complications (Hall, 2003; Hall et al., 1999; Agrawal et al., 2008; Kahn, 2008). Excessive long-term use of Na may also cause a secondary loss of Ca.

2.5. Phosphorus

Phosphorus (P) is present in vegetables in the range of 16.2–437 mg/100 g. The lowest content of P is shown in fruits, which are in the range 9.9–94.3 mg/100 g (Szefer and Grembecka, 2007). The phosphorus daily recommended intake is 800–1300 mg (<http://www.anyvitamins.com/rda.htm>). Phosphate (PO_4^{3-}) is required to produce ATP, GTP and CP as energetic substances and to regulate the activity of a number of proteins by means of phosphorylation reactions (Sobotka et al., 2008). Phosphorus is closely related to Ca homeostasis and also related to bone and teeth formation and the majority of the metabolic actions in the body, including kidney functioning, cell growth and the contraction of the heart muscle (Theobald, 2005; Szefer and Grembecka, 2007; Renkema et al., 2008). Deficiency of this element is unusual but symptoms are described as painful bones, irregular breathing, fatigue, anxiety, numbness, skin sensitivity and changes in body weight. If Ca supply is also deficient, then the condition may become severe because of increased risks of high blood pressure and bowel cancer. Ingesting dosages of P exceeding 3–4 g/day may be harmful as it can interfere with Ca absorption (Ghosh and Joshi, 2008; Moe, 2008).

2.6. Chromium

The concentration of chromium (Cr) generally ranges from 4×10^{-5} to 6×10^{-3} mg/100 g in vegetables and 0.005 to 0.018 mg/100 g in fruits (Szefer and Grembecka, 2007). A RDA for Cr is not well defined, but it is considered to be between 25–35 µg/day, fruits and vegetables being the major dietary contributors of Cr intake (<http://www.anyvitamins.com/rda.htm>). Because of its ‘micronutrient’ characteristics, it is difficult to differentiate its content in foods from improper food contaminations (Lukaski, 2004). It is well accepted that Cr is essential for normal blood glucose and lipid metabolism and an insulin-coadjuvant (Huskisson et al., 2007; Lukaski, 2004; Shenkin, 2008). Other biochemical actions for Cr such as involvement in gene expression, energy production, lipoprotein or lipid synthesis and metabolism regulation have been also described (Shenkin, 2008). Deficiencies in Cr are accompanied by glucose intolerance, weight loss and peripheral neuropathy (Shenkin, 2008). Moreover, low Cr levels may increase the risk of cardiovascular diseases (Thomas and Gropper, 1996). Chromium is not easily absorbed and shows low levels in the organism, explaining the absence of data on its toxicity. However, high doses of Cr have been related to chromosomal damage, alterations in the kidney and liver, and metallic-mineral disorders (Guerrero-Romero and Rodríguez-Morán, 2005).

2.7. Cobalt

There are not many data on levels of cobalt (Co) in foods of plant origin in the scientific literature. The available data showed low levels of this micronutrient, often un-

der 0.001 mg/100 g, with the lowest levels observed in vegetables (Szefer and Grembecka, 2007). The RDA for Co has been defined at around 300 micrograms (<http://www.anyvitamins.com/rda.htm>). Cobalt is required in the haematopoiesis of red blood cells and in preventing anaemia (Narasinga Rao, 2003). Its function is closely related to the physiological role of vitamin B12 in the production and maintenance of red blood cells. Moreover, Co stimulates appetite, and promotes growth and energy release (Kräutler, 2005; Mertz, 1981). Excessive intake of Co may damage the heart muscles, elevate the haemoglobin concentration, cause congestive heart failure and may cause damage to the thyroid gland, reducing its activity (Barceloux, 1999).

2.8. Copper

Low levels of copper (Cu) have been described in vegetables, ranging from 0.004 to 0.24 mg/100 g, except legumes, that can be up to 0.5 mg/100 g. Fruits contain small amounts of Cu, ranging from 0.01 to 0.24 mg/100 g (Szefer and Grembecka, 2007). The RDA of Cu ranges between 1.0 and 1.6 mg per day (<http://www.anyvitamins.com/rda.htm>). Copper primary functions are related to enzyme function including Phase-I detoxifying enzymes (i.e., the cytochrome C oxidase family of enzymes) (Huskisson et al., 2007; Guerrero-Romero and Rodríguez-Morán, 2005; Shenkin, 2008). In addition, Cu is also necessary for the development of connective tissue and nerve coverings (myelin sheath) (Guerrero-Romero and Rodríguez-Morán, 2005; Shenkin, 2008) and also participates in the Fe metabolism (Huskisson et al., 2007; Guerrero-Romero and Rodríguez-Morán, 2005). Copper may be accumulated in the adult body (liver and brain) up to a limit of 80 mg (Guerrero-Romero and Rodríguez-Morán, 2005), supporting deficient dietary intake, without inducing clinical symptoms of toxicity for a short period of time. Cu deficiency is not frequent in humans, although it can cause several haematological symptoms such as normocytic, hypochromic anaemia, leucopenia and neuropenia, and skeletal disturbances (Huskisson et al., 2007; Guerrero-Romero and Rodríguez-Morán, 2005). Toxic levels of Cu have been related to liver damage in chronic intoxication and gastrointestinal effects with cramps, nausea, diarrhoea and vomiting in acute episodes (Guerrero-Romero and Rodríguez-Morán, 2005).

2.9. Iron

Iron (Fe) contents in vegetables and fruits are low, varying from 0.13 to 3.01 mg/100 g. The iron in foods of plant origin is mostly present in the form of insoluble complexes of Fe^{3+} with phytic acid, phosphates, oxalates and carbonates. However, the bioavailability of the Fe present in foods is less than 8%. Nuts and cocoa powder may be a good source of Fe (16.1 and 25.8 mg/100 g, respectively; Szefer and Grembecka, 2007; <http://www.anyvitamins.com/rda.htm>). The recommended intake of iron is 8–18 mg per

day (<http://www.anyvitamins.com/rda.htm>). The major function of Fe is related to the synthesis of haemoglobin and myoglobin (Huskisson et al., 2007; Guerrero-Romero and Rodríguez-Morán, 2005; Shenkin, 2008). It is also required for energy production. The first reason for Fe deficiency is inadequate Fe intake (Lukaski, 2004). Severe Fe deficiency results in hypochromic anaemia (Huskisson et al., 2007; Guerrero-Romero and Rodríguez-Morán, 2005). Toxic levels of Fe in the body may be a consequence of genetic or metabolic disorders, frequent blood transfusions or excessive intake. An excess of Fe over a long period could result in liver and heart damage, diabetes, and skin changes (Fraga and Oteiza, 2002).

2.10. Manganese

Fruits and vegetables are also characterised by a low content of manganese (Mn). Vegetables contain Mn in the range 0.01–0.078 mg/100 g and fruits 0.01–0.66 mg/100 g (Szefer and Grembecka, 2007). The recommended intake of Mn is 2 mg/day (<http://www.anyvitamins.com/rda.htm>), and its main physiological function is being an enzyme co-factor involved in antioxidant reactions related to the glucose metabolism (metabolism of carbohydrates and gluconeogenesis; Huskisson et al., 2007; Guerrero-Romero and Rodríguez-Morán, 2005; Shenkin, 2008). Deficiencies in Mn are extremely rare but have shown a reduction in cholesterol, red blood cells and mucopolysaccharide abnormalities. Under experimental conditions signs of a scaly rash and low levels of plasma cholesterol have been observed (Shenkin, 2008). An excess of Mn produces a toxic effect in the brain, causing a Parkinson-like syndrome (Guerrero-Romero and Rodríguez-Morán, 2005; Shenkin, 2008).

2.11. Molybdenum

Molybdenum (Mo) is present in plant-based foods, normally at low levels. However, certain foods may concentrate extremely high levels of Mo. The range of variation between foods is very wide (from 1×10^{-6} mg/100 g in wine to 0.15 mg/100 g in peas). Canned vegetables contain up to 0.03 mg/100 g (Szefer and Grembecka, 2007). Doses < 250 µg are considered safe (<http://www.anyvitamins.com/rda.htm>). Molybdenum function is related to the turnover of amino acids and purine metabolism, assisting in the elimination of secondary dangerous compounds (nitrosamines). Furthermore, Mo is a cofactor for oxidant enzymes, especially sulphite oxidase and xanthine oxidase (Shenkin, 2008). A Mo deficiency constitutes a hereditary metabolic disorder characterised by severe neurodegeneration, resulting in early childhood death (Schwartz, 2005). Toxic quantities and excess of Mo may interfere with the metabolism of Co and might give symptoms of anaemia and slow growth (Xiao-Yun et al., 2006).

2.12. Nickel

Vegetables usually present nickel (Ni) levels in the range of 5×10^{-4} to 0.28 mg/100 g, and fruits between < 0.004 and 0.05 mg/100 g (Szefer and Grembecka, 2007). The recommended daily intake of Ni is in the range of 302–735 µg (Roychowdhury et al., 2003).

2.13. Selenium

The concentration of selenium (Se) ranges from 10^{-4} to 0.06 mg/100 g in foods of plant origin (Szefer and Grembecka, 2007). Seventy micrograms per day is taken as the required dosage for this micronutrient (<http://www.anyvitamins.com/rda.htm>). Selenium is an essential component of selenoproteins, which are implicated in antioxidant reactions (Guerrero-Romero and Rodríguez-Morán, 2005). In addition, although Se functions are not fully known, it seems that it also presents activity related to thyroid and immune system functions through its intervention (Shenkin, 2008). Selenium is associated with marked reductions in risks of several types of cancer (Combs, 2004) and its deficiency may contribute to heart disease, hypothyroidism and deficiencies in the immune system (Guerrero-Romero and Rodríguez-Morán, 2005; Combs, 2000; Zimmermann and Köhrle, 2002). An excess of Se has been related to several symptoms including: gastrointestinal upset, hair loss, fatigue and mild nerve damage. However, Se toxicity is not frequent and is related to accidental exposures (Guerrero-Romero and Rodríguez-Morán, 2005).

2.14. Zinc

The concentration of zinc (Zn) in plant-based foods generally varies from 0.05 to 11.8 mg/100 g. The lower levels of Zn are found in fresh fruits (0.02–0.61 mg/100 g). Fruit juices and beverages are characterised by low levels of Zn ranging from 0.01–0.27 mg/100 g (Szefer and Grembecka, 2007). Recommended daily Zn consumption ranges from 8–11 mg (<http://www.anyvitamins.com/rda.htm>; Lukaski, 2004). It is required for the structure and activity of more than 100 enzymes (Huskisson et al., 2007; Guerrero-Romero and Rodríguez-Morán, 2005; Shenkin, 2008), for the synthesis of nucleic acids and proteins, for cellular differentiation, and for glucose use and insulin secretion (Lukaski, 2004). This mineral takes part in the Zn fingers associated with DNA, haemoglobin, myoglobin and cytochromes (Guerrero-Romero and Rodríguez-Morán, 2005; Shenkin, 2008). The bioavailability of Zn is reduced by the presence of large amounts of other elements such as Fe or Cu (Shenkin, 2008). Zn deficiency is relatively frequent and well characterised, and the absence of Zn negatively affects the immune system efficacy, and the sensibility of taste and smell senses, and impairs DNA synthesis (Guerrero-Romero and Rodríguez-Morán, 2005; Shenkin, 2008). It has also been described that Zn deficiency produces hair loss and hypochromic anaemia (Shenkin, 2008). Zn toxicity shows both acute and chronic effects. Intakes of



Figure 2. Greenhouse experiment evaluating environmental stresses (salinity and drought) in horticultural crops.

150–450 mg per day over an extended period of time have been associated with poor Cu levels, altered Fe and immune functions, and reduced levels of HDL (Guerrero-Romero and Rodríguez-Morán, 2005; Hamilton et al., 2001).

3. ENVIRONMENTAL STRESS AFFECTING PLANT MINERAL CONTENT

Abiotic stresses such as high salt levels, low water availability and extreme temperatures can severely modify the mineral and nutritive quality of the crops for human consumption. These types of external stresses are becoming increasingly important because of the global reduction in the availability of water resources of good quality for irrigation, which indeed is affecting the plant mineral status and consequently, the nutritional quality of a given cultivar. To date, the reports have mainly studied the influence of environmental stresses on the carbohydrates (sugars), amino acids or antioxidant production of vegetables and fruits, and most investigations have been focused on salinity as the main abiotic stress. However, there is limited information about the influence of general abiotic factors on the mineral content of plant-based foods and food products as a bioindication of the food nutritive value and quality. In general, the mineral nutrient contents change when external conditions affect the plant growth (i.e., environmental stress) and there is a reduced plant growth and reduced biomass at harvest, accompanied by less dilution of nutrients on a dry mass basis (Fig. 2).

3.1. Salinity

The use of saline water for irrigation may affect the mineral composition of plants and, therefore, the fruit quality. In a saline environment, ion homeostasis can be disturbed by excessive uptake of Na^+ and Cl^- . Competition between these and further anions and cations has been well documented over the last 20 years (Sharpley et al., 1992; Lopez and Satti,

1996; De Pascale et al., 2005). Thus, in general, salinity reduces phosphate uptake and accumulation in crops as well as Ca^{2+} soil bioavailability and transport, which affects the quality of both vegetative and reproductive organs including fruits and edible parts of the plants. In addition, Na^+ and Cl^- ions may reduce K^+ and NO_3^- uptake, respectively (Grattan and Grieve, 1999). Under saline stress, a reduction in NO_3^- content has been observed in edible florets of broccoli (*Brassica oleracea* var. *italica*) and in tomato (*Solanum lycopersicon*) (Lopez-Berenguer et al., 2009) and although the reports on the effect of nitrate on human health are still conflicting, its reduction in foods could add a nutritional value to the cultivar of interest (Anjana and Iqbal, 2007). Also, in these reports, concentrations of Na^+ and Cl^- were higher in the leaves than in the florets, in agreement with the fact that under saline stress plants attempt to minimise the concentration of toxic ions in their reproductive organs (Hachicha et al., 2000). However, Del Amor et al. (2001) found that in tomato fruits, total anion Cl^- and NO_3^- concentrations increased by 11% as the salinity level increased from 2 to 8 $\text{dS}\cdot\text{m}^{-1}$ but fruit K^+ , Na^+ , Ca^{2+} and Mg^{2+} contents were reduced significantly by salinity levels. Interactions between salinity and fertilisation have been described and concentrations of P, K^+ , Mg^{2+} , Cu and Zn significantly decreased at high salinity and when urea was used as a nitrogen source. In this case, the total nitrogen concentration was not affected. Other studies on tomato and salinity showed that fruit Ca^{2+} was also decreased by salinity or NH_4^+ , with the negative effect of NH_4^+ being higher than the effect of salinity (Flores et al., 2003).

On the other hand, saline stress is a condition that may cause a combination of complex interactions affecting the plant metabolism or the inner nutritional requirements, but little information on the distribution of essential minerals in plants for foods grown under salinity has yet been published. Moreover, the effects of salinity on mineral contents are often equivocal depending on the species or cultivar and the specific plant organ (De Pascale et al., 2005). On this subject, it has been reported that salinity can originate stimulatory as well as inhibitory effects on the uptake of some micronutrients by

crop plants. Thus, as recently observed in two strawberry cultivars under salt stress, the mineral status of the berries was improved (increased Na^+ and Cl^- , as well as N and P contents), but a different response was detected for K^+ and Zn, which remained unaffected in the less-sensitive cultivar, and rose in the sensitive cultivar (Keutgen and Pawelzik, 2008).

The uptake of Fe, Mn, Zn and Cu generally increases in crop plants under salinity stress (Alam, 1994). However, the detrimental effects of NaCl stress on the nutrition of bean plants reflected differences in distinct plant organs and showed higher concentrations of Cl^- and Mn in roots, Cl^- , Fe and Mn in leaves, and Cl^- and Fe in fruits (Carbonell-Barrachina et al., 1998). Therefore, when applying moderate salinity levels for quality improvement, it is necessary to consider changes in the pool of mineral nutrients depending on the sensitivity of the cultivar and differences in mineral accumulation in the plant organs in order to avoid negative effects of the treatment.

In the fruits of courgette plants (*Cucurbita pepo* L. var. Moschata) an 80 mM NaCl treatment improved yield and fruit quality (Villora et al., 1999) and significantly increased the concentrations of micronutrients (Fe and Zn mainly) in the edible part of this crop (Villora et al., 2000). In addition, the concentrations of total Mn and total extractable Fe, Cu and Zn followed no linear pattern in response to the increased NaCl concentrations. These results for courgette contrast with findings for tomato, squash and green beans, in which the level of each microelement reportedly fluctuates with salinity, perhaps due in part not only to the salt treatments but also largely to the type of crop and the cultivar used in each experiment (Grattan and Grieve, 1999). In a recent report, Ca^{2+} , Mg^{2+} , K^+ and Mn contents decreased in the hot pepper fruits of a sensitive cultivar of *Capsicum annuum* L. as NaCl concentration increased (Ramirez-Serrano et al., 2008). Some studies on salinity in grafted plants of a “Star Ruby” grapefruit scion on two rootstocks, “Cleopatra” mandarin and “Carrizo” citrange, showed that fruits from saline treatment on “Carrizo” had Cl^- and Na^+ concentrations (2.87 and 1.6 times higher, respectively) than fruits from no saline treatments. Moreover, in the first harvesting, salinity increased K^+ concentration in the juice of fruits from trees grafted on “Carrizo” and treatments with 30 mM of NaCl decreased Ca^{2+} concentration in fruits from trees grafted with both rootstocks. However, salinity had no major effect on juice K^+ concentration on the second harvesting date or on juice Mg^{2+} concentration at both sampling times (García-Sánchez et al., 2003).

Plants respond to environmental stress by synthesising signalling molecules that activate a range of signal transduction pathways. Several such signalling molecules have been identified in plants such as Ca, jasmonic acid (JA), ethylene (C_2H_4) and salicylic acid (SA) derivatives. However, the effect of signalling molecules applied externally under stressful conditions (saline treatments) on the plant mineral uptake is not fully understood or well documented. Positive effects of SA on the ion uptake, and inhibitory effects on Na^+ and Cl^- uptake have been described for maize plants under salinity (Gunes et al., 2007). Similar effects of SA on the Na^+ , K^+ , Ca^{2+} and Mg^{2+} contents in wheat plants grown under salinity have been described (Al-Hakimi and Hamada, 2001).

In addition to its role as a cellular messenger, effects of Ca^{2+} on integrity of membranes, rigidity of the cell wall, and maintenance of cell-to-cell contact are reported. Supplemental Ca^{2+} has been successful in improving crop quality due to the correction of Ca^{2+} deficiencies induced by Na^+ . Under osmotic stress, the distribution of Ca^{2+} to the distal end of fruits is decreased, leading to a local deficiency of Ca^{2+} that causes rotting at the distal end of fruits known as blossom end rot (BER) (Ho et al., 1993; Saure, 2001; Guichard et al., 2001). However, BER is known to be affected not only by one factor, but also by interactions between water availability, salinity and nutrient ratios in the root zone, and the product of average daily solar radiation and air temperature, root temperature and air humidity (Adams and Ho, 1993; Ehret and Ho, 1986). In apples, it has also been observed that low Ca contents are associated with bitter pit disease (Fucumoto et al., 1987) or pit breakdown (Tomala and Dilley, 1990).

In general, salinity influences the uptake and transport of other ions by the plant and such antagonism could occur between Na^+ and Ca^{2+} , K^+ or Mg^{2+} and between Cl^- and NO_3^- . These effects may be involved in the occurrence of nutritional disorders in plant tissues, affecting food quality.

3.2. Drought

Limited water supply in many areas of the world, especially in arid and semiarid regions, is a major problem in irrigated agriculture. In recent years, it has become clear that the maintenance of a slight water deficit can improve the partitioning of carbohydrates to reproductive structures such as fruit and also control excessive vegetative growth (Chalmers et al., 1981). This is called “regulated deficit irrigation”, consisting of irrigation input being removed or reduced for specific periods during the growth cycle of crops (Chalmers et al., 1986). This technique results in more efficient use of irrigation water and often improves product quality (Turner, 2001). Rouphael et al. (2008) showed that using three different levels of irrigation based on evapotranspiration (ET) rates (1.0, 0.75 and 0.5 ET) and two grafting treatments on watermelon plants no significant differences among treatments were observed for P and Ca^{2+} concentrations, whereas K^+ and Mg^{2+} concentrations were significantly improved by both the irrigation rate and grafting combination with no significant differences between irrigation and grafting interaction.

Drought and salinity can differentially affect the mineral nutrition of plants. While salinity may cause nutrient deficiencies or imbalances, due to the competition of Na^+ and Cl^- with other nutrients such as K^+ , Ca^{2+} and NO_3^- , drought can affect nutrient uptake and impair translocation of some nutrients.

It has been recently reported that in banana, the main effect of drought was to reduce K^+ levels, which is the major mineral nutrient in this fruit. By contrast, the content of certain elements increased (i.e., Ca^{2+} , Na^+ , Fe and Zn), or remained stable (i.e., N, P, Mg^{2+} , Mn and Cu) under the drought treatment, which also generated a positive effect on the organoleptic properties of the fruit (Mahouachi, 2007). After rehydration, the mineral content of the bananas was similar

between stressed and non-stressed plants. These data illustrate the ability of this cultivar to maintain relatively normal levels of minerals and functional fruit tissues after dehydration despite the long period of water stress. Nonetheless, the fruits lost their commercial value to a certain degree (reduced size and biomass) after the period of water stress.

Wild plants play an important role in the diet of inhabitants in different parts of the world. These plants tend to be drought-resistant and are gathered both in times of abundance and times of need, and for this reason numerous reports have been focused on wild edible plants. In a study of dietary practices in Northeastern Nigeria, it was observed that the edible wild species available during the wet season generally were inferior in micronutrient mineral contents compared with the dry season plants (Lockett et al., 2000). Commonly consumed species of edible wild barks, fruits, leaves, nuts, seeds, and tubers were analysed and Kuka bark (*Adansonia digitata*), given to infants, was high in Ca^{2+} , Cu, Fe and Zn. Cediya (*Ficus thonningii*), dorowa (*Parkia biglobosa*) and zogale (*Moringa oleifera*) were also good sources of Ca^{2+} , Fe, Cu and Zn. Fruits, leaves and nuts of aduwa (*Balanites aegyptiaca*) are widely used during the dry and drought seasons. Tsamiya seeds (*Tamarindus indica*), consumed commonly during pregnancy, were good sources of Zn, and Kirya seeds (*Prosopis africana*) contained the highest Zn concentrations. Shiwaka leaves (*Veronia colorate*), consumed by pregnant women to increase breastmilk production, were high in P, Mg^{2+} and Ca^{2+} .

In another report it has been illustrated that the mineral content of some edible wild leaves contained higher N, K^+ , Ca^{2+} and Mg^{2+} concentrations than those of some commonly used vegetables such as spinach (*Spinacia oleracea*), pepper (*Capicum annum*), lettuce (*Lactuca* spp.) and cabbages (*Brassica oleracea*). However, P, S and Na^+ contents were lower, and Fe, Mn, Zn and Cu levels were equal (Turan et al., 2003).

The time of application as well as the duration of water stress during the fruit development can influence the mineral content. In 'Williams' pears a reduced water supply at the end of the fruit development (late water stress) caused smaller reductions in the uptake of Ca^{2+} , K^+ and B within the fruits, while at the beginning of fruit development (early water stress) only a lower content of Ca^{2+} was observed in the fruits. Reduced water supply either at the beginning or the end of the productive cycle induced a higher N content in the fruits. In the treatment of early water stress the K contents were higher than in the untreated controls (Hudina and Stampar, 2000).

The potential of roots to absorb nutrients generally declines in water-stressed plants, presumably due to a decline in nutrient element demand, but the ability to take up and transport the mineral nutrients differs in distinct crops and depends on the plant's tolerance to drought.

3.3. Extreme temperatures

It is evident that the roots play a principal role in the absorption of the mineral elements that will be translocated to the aerial parts of the plant. In general, a consistent decrease

in the nutrient concentrations in the plant shoots is parallel to the growth suppression at low root temperatures. Growth and mineral composition of fruits in potted trees were studied at two temperatures (19 and 24 °C) in 'Golden Delicious' and in 'Cox's Orange Pippin' apples (*Malus domestica*) (Tromp, 1975). In this report the levels of K, N, Mg and P were increased at the higher temperature. With respect to Ca, the high temperature regime reduced its influx in 'Golden Delicious' but favoured the Ca influx in the 'Cox's Orange Pippin' apples. Similarly, in two cultivars of tomato with contrasting response to elevated temperature, Ca was poorly transported to the fruits but in fruit explants, the elevated temperature (40 °C) increased the Ca import into the fruits in both cultivars. This permanent flux of Ca to the fruits may have a pivotal role in maintaining an optimal level of Ca^{2+} in the cytoplasm of fruit cells, as a factor for increasing the tolerance to high temperatures (Starck et al., 1994). On the other hand, only a few studies have examined the effect of differences in temperature regimes between day and night on the mineral status of fruits or vegetable foods, but low concentration of nitrate was observed as a consequence of variations in temperature in root and shoot Ca^{2+} due to lower night air temperatures (Gent and Ma, 2000).

3.4. Light intensity

A certain influence of the light on the transport of nutrients from shoots to the fruit through the transpiration stream has been suggested in different studies. Caruso et al. (2004) reported that shading caused a reduction in the content of the main mineral elements except for nitrates in strawberry fruits. Also, the effects of sunlight on the mineral contents of apples were investigated (Iwane and Bessho, 2006). The treatment of sunlight from East and West directions on 75 apples from the inside and outside of the crown of the trees revealed a significant negative correlation between the amount of solar radiation received by the fruit and its mineral content for K^+ , Ca^{2+} and Zn. The concentration of minerals in apples grown on the inside was higher than in the fruits grown outside of the crown. The concentration of minerals was higher in apples grown on the shaded side than in the apples grown on the sunny side. No significant differences in mineral concentrations were observed between fruit grown on the East or West orientation.

Effects of exposure to light and air movement on the accumulation of some mineral elements in fruits of kiwifruit (*Actinidia deliciosa* var. *deliciosa*) have been presented (Montanaro et al., 2006), where the main differences were found for Ca^{2+} , exhibiting twice the content in exposed fruits (> 40% full sunlight) than in shaded fruit (< 20% full sunlight).

Light is one of the main external factors influencing the nitrate concentrations in vegetables. Several human health hazards due to nitrate toxicity have been identified. The accumulation of nitrate in the plant tissues is more frequent under poor light conditions in leafy vegetables such as lettuce, spinach or kohlrabi (*Brassica oleracea* var. *gongylodes* L.) (Blom-Zandra and Lampe, 1985; Steingröver et al., 1986; Sritharan and Lenz,

1992). A controlled nutritional regime is then needed to reduce the leaf nitrate in the leaves (i.e., lettuce) under such unfavourable light conditions (Demsar et al., 2004).

Anjana et al. (2006) have reported that nitrate concentration was lowest at noon on a sunny day in spinach leaves. Thus, the time at which plants contain the lowest nitrate concentration may vary with the environmental conditions in different geographical regions of the world, and also depends on the interaction with other environmental factors. Santamaria et al. (1999) observed in different fresh vegetables that under conditions of low light availability, an increase in temperature increases the nitrate accumulation.

4. FERTILISATION PRACTICES AND MINERAL CONTENT IN FOOD CROPS

The supply of essential nutrients for the health of consumers by improving the fertilising practices in the productive sector has awakened great interest in recent years. Here, we will summarise the available information on the effects of fertiliser applications on the mineral content of crops in relation to food quality for human consumption.

4.1. Nitrogen fertilisation

The effect of N fertilisers on the mineral content of edible parts or fruits and vegetables is variable depending on the doses applied, the nutrient analysed, the species under study, and the organ to be consumed. Thus, in tomato grown under different N doses (0, 60, 120 and 180 hg ha⁻¹ N), only the higher N doses increased total fruit N levels but, antagonistically, K⁺ levels decreased continuously with the increased N (Cserni et al., 2008). In tuber and root crops such as potato (*Solanum tuberosum* L.) and sweet potato (*Ipomoea batatas* L.), which have enlarged underground stems and roots as edible parts, the application of N fertilisers usually led to increased tuber N concentration (Eppendorfer and Eggum, 1994). Also, the content of elements such as K⁺, P, Ca²⁺ and Mg²⁺ in mature tubers of potato was not significantly different to the untreated tubers after N fertilisation (0–200 kg.ha⁻¹) (Ilin et al., 2002). In contrast, in broccoli sprouts (*Brassica oleracea* var. Italica), higher S concentrations were found when increasing N and S fertilisation rates up to a determined dose of N and S, but higher N rates did not yield higher S uptake (Aires et al., 2007).

In experiments studying the influence of the NH₄⁺/NO₃⁻ ratio in the nutrient solution and its effects on mineral status (in *Brassica oleracea* var. Italica), when this ratio was 0.5:0.5, the concentrations of P, K⁺, Ca²⁺ and Mg²⁺ were all higher in cabbage roots and leaves than those in plants grown in nutrient solutions with different ratios of decreased NH₄⁺ supply (Zhang et al., 2007).

It is well known that the application of N improves plant growth and yield. However, the application of high concentrations of N not only contaminates the environment, but also causes NO₃⁻ accumulation in the leaves of vegetable crops,

which have been found to be the major source of toxic NO₃⁻ uptake by humans. In general, vegetables that are consumed with their roots, stems and leaves have a high NO₃⁻ accumulation, whereas those with only fruits as the edible part have low NO₃⁻ accumulation rates (Zhou et al., 2000). In addition, NO₃⁻ contents vary depending on the organ of the plant (Santamaria et al., 1999; Anjana et al., 2006) and the physiological age of the plant (Maynard et al., 1976; Anjana et al., 2006). Field experiments have shown that NO₃⁻ concentrations in leafy vegetables were positively correlated with N rates, and N fertiliser added to the soil was the major cause of NO₃⁻ accumulation in vegetables (Wang et al., 2001). In the same way, Zhang et al. (2007), and Staugatis et al. (2008) found a linear increase in NO₃⁻ concentration with increasing N fertilisation in cabbage (*Brassica campestris*) leaves and roots, and heads, respectively.

4.2. Phosphorus fertilisation

Phosphorus promotes root growth, enhances nutrient and water-use efficiency, and increases yield. Therefore, since absorption and reduction of NO₃⁻ is a process which consumes ATP, the metabolism of NO₃⁻ is related to P supply. In pot experiments, it has been observed that a high soil N:P ratio was one of the key causes of NO₃⁻ accumulation in vegetables (Gao et al., 1989). In contrast, P fertilisation decreased NO₃⁻ concentration in cabbage (*Brassica campestris*) and canola (*Brassica napus*), and had no significant effect in spinach (*Spinacia oleracea*) (Wang and Li, 2004).

Togay et al. (2008) studied the effect of different doses of P (10, 40 and 80 kg ha⁻¹) on the P content in grain of dry bean (*Phaseolus vulgaris*) and observed increased P levels when 80 kg ha⁻¹ P was applied. When looking at the micronutrients, Moreno et al. (2003) found that Fe and Mn concentrations in cucumber were higher in P-fertilised treatments compared with the unfertilised control. This effect is similar to what was found with edible fruits such as apple (*Malus sylvestris* Mill var. *domestica* (Borkh.)) where increased fruit P was obtained with P treatments. On the contrary, in cereals Komljenovic et al. (2006) revealed that maize grain (*Zea mays*) was less dependent on P fertilisation compared with the leaf; and it has also been shown in pear (*Pyrus communis*) that foliar P fertilisation decreased the content of B and Zn in fruits (Hudina and Stampar, 2002).

4.3. Potassium fertilisation

Potassium is closely related to N assimilation in plants and can accelerate transport of NO₃⁻ from roots to aboveground plant parts. Thus, Zhou et al. (1989) showed that compared with the control, NO₃⁻ concentration in cabbage (*Brassica campestris*) decreased with the application of K⁺, whereas it increased in spinach (*Spinacia oleracea*) (Gao et al., 1989).

In relation to other minerals, K⁺ fertilisation has different effects. In fact, Hudina and Stampar (2002) showed that foliar fertilisation with K⁺ increased the content of K in pears

(*Pyrus communis* L.), whereas K^+ concentrations in broccoli heads (*Brassica oleracea* var. Italica) showed no differences among four levels of K^+ fertilisation (Vidal-Martínez et al., 2006). In other studies, the concentrations of B and Zn in pears (Hudina and Stampar, 2002) as well as N concentrations in potato (*Solanum tuberosum*) and sweet cabbage (Eppendorfer and Eggum, 1994) decreased with increased K^+ fertilisation.

4.4. Sulphur fertilisation

Sulphur fertilisation may be recommended for certain crops to reduce the undesirable NO_3^- contained in their edible parts. In fact, an increased soil S level significantly reduced NO_3^- concentrations in tubers and leaves of kohlrabi (Losak et al., 2008), and turnip tops (*Brassica rapa* L.) (De Pascale et al., 2007). In S-deficient soils, the application of S fertilisers can decrease the tuber N concentration in potato (*Solanum tuberosum*) due to increased dry mass yield (Eppendorfer and Eggum, 1994). Nevertheless, in a greenhouse pot experiment using 'Luna' kohlrabi (*Brassica oleracea*), the effect of S fertilisation on N content in tubers and leaves was insignificant (Losak et al., 2008).

4.5. Calcium fertilisation

Leafy vegetables can be an excellent dietary source of calcium, and are a good alternative for individuals with a diet low in dairy products. Increasing the calcium content in leafy vegetables through fertilisation management could further improve their nutritional benefits. Thus, it has been observed that in lettuce produced in a hydroponic system an increase in Ca^{2+} concentration in the nutrient solution increased the Ca^{2+} levels in the leaves (Neeser et al., 2007).

It has also been shown that Ca^{2+} application increased Ca^{2+} concentrations in peripheral layers of apple fruits and reduced K^+ concentrations (Grimm-Wetzel and Schonherr, 2007). Similar results were reported by Val et al. (2008), where Ca^{2+} treatments increased the concentration of Ca^{2+} in the skin, but not in the flesh of fruit, and several sprays were needed to promote a prolonged increase in the concentration of Ca^{2+} in the skin. However, Ca^{2+} sprays did not influence the concentrations of Mg^{2+} and K^+ . In a recent study the application of $CaCl_2$ increased the Ca^{2+} content in litchi fruit; firmness and skin colour were affected, and some positive correlations with leaf and fruit K^+ were detected (Cronje et al., 2009).

In kiwifruit, fruit quality is associated with the correct Ca^{2+} level; however, the application of a biostimulant such as Ca^{2+} fertiliser, which is recommended to prevent calcium deficiency resulting from lack of uptake into fruit, did not affect fruit yield (Otero et al., 2007).

4.6. Microelement fertilisation

Although the majority of experiments have been performed using the widely distributed N, P and K^+ fertilisers, there are

also a few pieces of information about the effects of microelement fertilisers on the edible parts of plants for human consumption (Baize et al., 2009). Graham et al. (2001) showed that application of Zn fertiliser to Zn-deficient soil at sowing significantly increased the Zn concentration in wheat grain. Also, the content of Zn and several other micronutrients, such as I, Se, Cu and Ni, was usually enhanced by application of the appropriate mineral forms (Wang et al., 2008). Micronutrient foliar fertilisation seems to be a cheap and effective method, depending on the nutrient supplied and the time of application. In this way, Wojcik and Wojcik (2003) showed that foliar B sprays before full bloom or after harvest increased B concentrations in fruitlets of pear (*Pyrus communis* L.) at 40 days after flowering.

Selenium deficiency is a very serious nutritional and health problem. That is why the effect of selenite and selenate fertilisation on Se content has been widely studied (Chen et al., 2002; Fang et al., 2008; Ducsay et al., 2009). In reported experiments, selected mineral contents were higher with application of selenate than selenite to certain species. Thus, a higher content of Se in rice (*Oryza sativa*) (Chen et al., 2002) and S in lettuce plants (*Lactuca sativa* cv. Philipus) (Ríos et al., 2008) were found. Other studies showed that differentiated doses of selenite in soil caused a significant increase in Se content in dry matter of wheat grain (Ducsay et al., 2009), whereas non-significant effects were observed in lettuce (Ríos et al., 2008). In addition, Fang et al. (2008) indicated that Zn and Se were the main variables increasing the Zn, Se and Fe contents of rice. Therefore, the application of Zn, Se and Fe mixed fertiliser as foliar spray could alleviate the physiological deficiency of these micronutrients in rice.

4.7. Organic farming versus mineral fertilisation

The massive use of chemical fertilisers in intensive agriculture has greatly increased concern for the declining fertility of soils. Soil nutrient depletion is the result of increasing pressure on agricultural land (Wopereis et al., 2006; Lal, 2009). That is why organic inputs are required to ensure that intensive systems do not threaten the sustainability of land use. However, small farmers are reluctant to use organic wastes or composts because organic fertilisers do not release nutrients as fast as mineral fertilisers and they do not supply a balanced ratio of nutrients at the right time (Bath, 2000; Kirchmann et al., 2002; Gunnarsson, 2003). However, demand for organically-grown products has risen steadily and the number of growers adopting organic farming systems has also increased, because organic foods are believed to be more nutritious than conventionally-grown foods, with a better balance of vitamins and minerals. Nevertheless, the scientific community has not conclusively shown that organic products are more nutritious than conventionally-grown foods (Winter and Davis, 2006). Thus, it seems to be important to see how organic and inorganic fertilisers affect food quality in terms of mineral content. Also, the negative effects that fertilisers have on food quality must be considered, since the anthropogenic activities aimed

at enhancing food production may facilitate the accumulation of undesirable substances.

Several experiments have been performed in order to compare the effects of organic and conventional (mineral) fertilisers on the crop yield and nutritional status of plants, since organic yields are often lower compared with conventional production (Mäder et al., 2002; Dumas et al., 2003; Gopinath et al., 2008).

Usually, the organic-amended soils showed significantly higher soil mineral content (Edmeades, 2003). However, other authors indicated lower mineral contents for organically fertilised soils (Gosling and Shepherd, 2005).

The influence of organic soil fertilisation on nutrient content in crops has been studied and different results have been recorded. Some authors showed that the application of organic amendments improved the soil nutrient content, but did not always increase the plant nutrient concentration (Roe, 1998; Warman, 2005) since it depends on the crop type, the nutrient used, the climate parameters and the year of the study (Warman and Havard, 1997, 1998; Maqueda et al., 2001). Furthermore, the available scientific literature shows that some of the comparisons are not experimentally valid due to variation in crop varieties, timing in fertilisation, and handling and storage after harvesting (Warman and Havard, 1997). However, there are certain results that support that higher P and K⁺ contents in wheat grain were obtained by applying organic amendments than the elemental contents using mineral fertilisers instead (Colla et al., 2002; Wszelaki et al., 2005; Gopinath et al., 2008; Basu et al., 2008).

The long-term use of organic composts (vegetal compost and green residue of previous crops) on greenhouse soils induced few differences in the macronutrient concentrations in the edible parts of food crops compared with the experiments using mineral fertilisation, although there was a trend of showing higher N concentration in minerally-grown crops and higher K⁺ concentration in organically-grown crops (Herencia et al., 2007). Moreover, the NO₃⁻ concentrations in the edible parts of organically-grown crops were significantly lower than in the minerally-fertilised plots (Vogtmann et al., 1993; Williams, 2002; Malmauret et al., 2002; Hajslova et al., 2005). This can provide a clear benefit for human health. Nevertheless, the results were variable depending on the crop, season cycle and year, and these factors must be considered carefully in the conclusions and potential recommendation to producers and consumers.

5. CONCLUSION

The quality of edible fruits concerning mineral contents may vary depending on interactions between cultivars, environmental factors such as light and temperature, composition of the nutrient solution, crop management practices, and the interaction of all these factors. This is the reason why all of them must be taken into account in order to characterise the nutritional value (mineral status) of fruits and vegetables, as well as the factors influencing the content of a specific element in a given cultivar. In addition, the physiological parameters of

the fruit (stage of development, ripening, marketable maturity, physiological maturity, senescence) and the plant or tree as a whole are also of interest.

The influence that fertilisation practices may have on the mineral status and nutritive value of fruits and vegetables also depends on the fertiliser used, the macro- (i.e., N, P, K, S, etc.) or micronutrient (i.e., Fe, Mn, Zn, Cu, Ni, Co, Se, etc.) studied, and the plant part of interest for consumption (i.e., leaf, root, tuber, fruit). Similarly, a determined or programmed pattern cannot be established for the use of irrigation regimes with waters of different qualities. Nonetheless, fertilisation seems to remain one of the most practical and effective ways to control and improve the nutritional value of crops to meet the needs of the population, as well as proper water management integrating practices for food quality and safety. A large body of research results has been performed in the past decades on the effects of distinct agronomical practices on specific crops of human interest, but more concise and precise studies are needed to improve the load of essential microelements in foods and to prevent or avoid the accumulation of toxic or undesirable contaminants.

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REFERENCES

- Adams P., Ho L.C. (1993) Effects of environment on the uptake and distribution of calcium in tomato and on the incidence of blossom-end rot, *Plant Soil* 154, 127–132.
- Agrawal V., Agarwal M., Joshi S.R., Ghosh A.K. (2008) Hyponatremia and hypernatremia: Disorders of water balance, *J. Assoc. Physicians India* 56, 956–964.
- Ahokas R.A., Sun Y., Bhattacharya S.K., Gerling I.C., Weber K.T. (2005) Aldosteronism and a proinflammatory vascular phenotype: Role of Mg²⁺, Ca²⁺, and H₂O₂ in peripheral blood mononuclear cells, *Circulation* 111, 51–57.
- Aires A., Rosa E., Carvalho R., Haneklaus S., Schnug E. (2007) Influence of nitrogen and sulfur fertilization on the mineral composition of broccoli sprouts, *J. Plant Nutr.* 30, 1035–1046.
- Alam S.M. (1994) Nutrient uptake by plants under stress conditions, in: Pessarakli M. (Ed.), *Handbook of plant and crop stress*, Marcel Dekker, New York, pp. 227–246.
- Al-Hakimi A.M.A., Hamada A.M. (2001) Counteraction of salinity stress on wheat plants by grain soaking in ascorbic acid, thiamin or sodium salicylate, *Biol. Plant.* 44, 253–261.
- Anjana U.S., Iqbal M. (2007) Nitrate accumulation in plants, factors affecting the process, and human health implications. A review, *Agron. Sustain. Dev.* 27, 45–57.
- Anjana U.S., Iqbal M., Abrol Y.P. (2006) Are nitrate concentrations in leafy vegetables within safe limits? Proceedings of the Workshop on Nitrogen in Environment, Industry and Agriculture, New Delhi, India, pp. 81–84.
- Baize D., Bellanger L., Tomassone R. (2009) Relationships between concentrations of trace metals in wheat grains and soil, *Agron. Sustain. Dev.* 29, 297–312.

- Barceloux D.G. (1999) Cobalt, J. Toxicol. Clin. Toxicol. 37, 201–216.
- Basu M., Bhadoria P.B.S., Mahapatra S.C. (2008) Growth, nitrogen fixation, yield and kernel quality of peanut in response to lime, organic and inorganic fertilizer levels, Bioresource Technol. 99, 4675–4683.
- Bath B. (2000) Matching the availability of N mineralisation from green-manure crops with the N-demand of field vegetables, Ph.D. Thesis, Swedish University of Agricultural Sciences, Uppsala, Sweden.
- Blom-Zandra M., Lampe J.E.M. (1985). The role of nitrate in the osmoregulation of lettuce (*Lactuca sativa* L.) grown at different light intensities, J. Exp. Bot. 36, 1043–1052.
- Bo S., Pisu E. (2008) Role of dietary magnesium in cardiovascular disease prevention, insulin sensitivity and diabetes, Curr. Opin. Lipidol. 19, 50–56.
- Carbonell-Barrachina A.A., Burlo F., Mataix J. (1998) Response of bean micronutrient to arsenic and salinity, J. Plant Nutr. 21, 1287–1299.
- Caruso G., Villari A., Villari G. (2004) Quality characteristics of “*Fragaria vesca* L.” fruits influenced by NFT solution EC and shading, Acta Hort. 648, 167–174.
- Chalmers D.J., Burge G., Jerie P.H., Mitchell P.D. (1986) The mechanism of regulation of Bartlett pear fruit and vegetative growth by irrigation withholding and regulated deficit irrigation, J. Am. Soc. Hortic. Sci. 111, 904–907.
- Chalmers D.J., Mitchell P.D., Vanheek L. (1981) Control of peach tree growth and productivity by regulated water supply, tree density and summer pruning, J. Am. Soc. Hortic. Sci. 106, 307–312.
- Chen L., Yang F., Xu J., Hu Y., Hu Q., Zhang Y., Pan G. (2002) Determination of selenium concentration of rice in china and effect of fertilization of selenite and selenate on selenium content of rice, J. Agr. Food Chem. 50, 5128–5130.
- Colla G., Mitchell J.P., Poudel D.D., Temple S.R. (2002) Changes of tomato yield and fruit elemental composition in conventional, low input, and organic systems, J. Sustain. Agr. 20, 53–67.
- Combs G.F. Jr. (2000) Food system-based approaches to improving micronutrient nutrition: The case for selenium, Biofactors 12, 39–43.
- Combs G.F. Jr. (2004) Status of selenium in prostate cancer prevention, Br. J. Cancer 91, 195–199.
- Cronje R.B., Sivakumar D., Mostert P.G., Korsten L. (2009) Effect of different preharvest treatment regimes on fruit quality of litchi cultivar “Maritius”, J. Plant Nutr. 32, 19–29.
- Cserni I., Peto J.B., Huvely A., Nemeth T., Vegh K.R. (2008) Nitrogen, phosphorus, potassium, acid, sugar and vitamin C content in tomato grown in different soil types and under different nitrogen doses, Cereal Res. Commun. 36, 1415–1418.
- De Pascale, S., Maggio, A., Barbieri, G. (2005) Soil salinization affects growth, yield and mineral composition of cauliflower and broccoli, Eur. J. Agron. 23, 254–264.
- De Pascale S., Maggio A., Fogliano V., Ambrosino P., Ritieni A. (2001) Irrigation with saline water improves carotenoids content and antioxidant activity of tomato, J. Hortic. Sci. Biotech. 76, 447–453.
- De Pascale S., Maggio A., Pernice R., Fogliano V., Barbieri G. (2007) Sulphur fertilization may improve the nutritional value of *Brassica rapa* L. subsp. *sylvestris*, Eur. J. Agron. 26, 418–424.
- Del Amor F.M., Martínez V., Cerdá A. (2001) Salt tolerance of tomato plants as affected by stage of plant development, Hortscience 37, 1260–1263.
- Demars J., Osvald J., Vodnik D. (2004) The effect of light-dependent application of nitrate on the growth of aeroponically grown lettuce (*Lactuca sativa* L.), J. Am. Soc. Hortic. Sci. 129, 570–575.
- Ducsay L., Lozek O., Varga L. (2009) The influence of selenium soil application on its content in spring wheat, Plant Soil Environ. 55, 80–84.
- Dumas Y., Dadomo M., Di Lucca G., Grolier P. (2003) Effects of environmental factors and agricultural techniques on antioxidant content of tomatoes, J. Sci. Food Agr. 83, 369–382.
- Durlach J., Bac P., Durlach V., Rayssiguier Y., Bara M., Guiet-Bara A. (1998) Magnesium status and ageing: An update, Magnesium Res. 11, 25–42.
- Edmeades D.C. (2003) The long-term effects of manures and fertilisers on soil productivity and quality: A review, Nutr. Cycl. Agroecosyst. 66, 165–180.
- Ehret D.L., Ho L.C. (1986) Effects of osmotic potential in nutrient solution on diurnal growth of tomato fruit, J. Exp. Bot. 37, 1294–1302.
- Eppendorfer W.H., Eggum B.O. (1994) Dietary fibre, starch, amino acids and nutritive value of potatoes as affected by sulfur, nitrogen, phosphorus, potassium, calcium and water stress, Acta Agr. Scand. B Soil Plant Sci. 44, 107–115.
- Fang Y., Wang L., Xin Z., Zhao L., An X., Hu Q. (2008) Effect of foliar application of zinc, selenium, and iron fertilizers on nutrients concentration and yield of rice grain in china, J. Agr. Food Chem. 56, 2079–2084.
- Flores P., Navarro J.M., Carvajal M., Cerdá A., Martínez, V. (2003) Tomato yield and quality as affected nitrogen source and salinity, Agronomía 23, 1–8.
- Fraga C.G., Oteiza P.I. (2002) Iron toxicity and antioxidant nutrients, Toxicology 180, 23–32.
- French R.J., Zamponi G.W. (2005) Voltage-gated sodium and calcium channels in nerve, muscle, and heart, IEEE T. Nanobiosci. 4, 58–69.
- Fukumoto M., Nagai K., Yoshioka H., Aoba K. (1987) Mechanism of the development of a calcium-related disorder (bitter pit) in apple, Jpn Agric. Res. Q. 20, 248–252.
- Gao Z.M., Zhang Y.D., Zhang D.Y., Shi R.H., Zhang M.F. (1989) Effects of N, P and K on the accumulation of nitrate and the activity of nitrate reductase and superoxidase in leafy vegetables, Acta Hort. Sin. 16, 293–298.
- García-Sánchez F., Carvajal M., Cerdá A., Martínez V. (2003) Response of “Star Ruby” grape fruit on two rootstocks to NaCl salinity, J. Hortic. Sci. Biotech. 78, 859–865.
- Gent M.P.N., Ma Y.Z. (2000) Mineral nutrition of tomato under diurnal temperature variation of root and shoot, Crop Sci. 40, 1629–1636.
- Ghosh A.K., Joshi S.R. (2008) Disorders of calcium, phosphorus and magnesium metabolism, J. Assoc. Physicians India 56, 613–621.
- Gopinath K.A., Saha S., Mina B.L., Pande H., Kundu S., Gupta H.S. (2008) Influence of organic amendments on growth, yield and quality of wheat and on soil properties during transition to organic production, Nutr. Cycl. Agroecosyst. 82, 51–60.
- Gosling P., Shepherd M. (2005) Long-term changes in soil fertility in organic arable farming systems in England, with particular reference to phosphorus and potassium, Agr. Ecosyst. Environ. 105, 425–432.
- Graham R.D., Welch R.M., Bouis H.E. (2001) Addressing micronutrient malnutrition through enhancing the nutritional quality of staple foods: principles, perspectives and knowledge gaps, Adv. Agron. 70, 77–142.
- Grattan S.R., Grieve C.M. (1999) Mineral nutrient acquisition and response by plants grown in saline environments, in: Pessarakli M. (Ed.), Handbook of Plant and Crop Stress, Marcel Dekker, New York, pp. 203–226.
- Grimm-Wetzel P., Schonherr J. (2007) Applications of calcium chloride to apple fruits increase calcium and reduce potassium concentrations in peripheral layers of fruits, Erwerbs-Obstbau 49, 75–83.

- Grusak M.A., Cakmak I. (2005) Methods to improve the crop delivery of minerals to human and livestock, in: Broadley M.R., White P.J. (Eds.), *Plant Nutritional Genomics*, Blackwell, pp. 265–286.
- Guerrero-Romero F., Rodríguez-Morán M. (2005) Complementary therapies for diabetes: The case for chromium, magnesium, and antioxidants, *Arch. Med. Res.* 36, 250–257.
- Guichard S., Bertin N., Leonardi C., Gary C. (2001) Tomato fruit quality in relation to water and carbon fluxes, *Agronomie* 21, 385–392.
- Gunes A., Inal A., Alpaslan M., Eraslan F., Bagci E.G., Cicek N. (2007) Salicylic acid induced changes on some physiological parameters symptomatic for oxidative stress and mineral nutrition in maize (*Zea mays* L.) grown under salinity, *J. Plant Phys.* 164, 728–736.
- Gunnarsson S. (2003) Optimisation of N release – Influence of plant material chemical composition on C and N mineralization, Ph.D. Thesis, Swedish University of Agricultural Sciences, Uppsala, Sweden.
- Hachicha M., Cheverry C., Mhiri A. (2000) The impact of long-term irrigation on changes of ground water level and soil salinity in northern Tunisia, *Arid. Soil Res. Rehab.* 14, 175–182.
- Hajslova J., Schulzova V., Slanina P., Janné K., Hellenäs K.E., Andersson C. (2005) Quality of organically and conventionally grown potatoes: Four year study of micronutrients, metals, secondary metabolites, enzymic browning and organoleptic properties, *Food Addit. Contam.* 19, 524–532.
- Hall J.E. (2003) The kidney, hypertension, and obesity, *Hypertension* 41, 625–633.
- Hall J.E., Brands M.W., Henegar J.R. (1999). Mechanisms of hypertension and kidney disease in obesity, *Ann. N.Y. Acad. Sci.* 892, 91–107.
- Hamilton I.M.J., Gilmore W.S., Strain J.J. (2001) Marginal copper deficiency and atherosclerosis, *Biol. Trace Elem. Res.* 78, 179–189.
- Herencia J.F., Ruiz-Porras J.C., Melero S., Garcia-Galavis P.A., Morillo E., Maqueda C. (2007) Comparison between organic and mineral fertilization for soil fertility levels, crop macronutrient concentrations, and yield, *Agron. J.* 99, 973–983.
- Ho L.C., Belda R., Brown M., Andrews J., Adams P. (1993) Uptake and transport of calcium and the possible causes of blossom-end rot in tomato, *J. Exp. Bot.* 44, 509–518.
- Hudina M., Stampar F. (2000) Influence of water regimes and mineral contents in soil upon the contents of minerals, sugars and organic acids in pear fruits (*Pyrus communis* L. Cv. 'Williams'), *Phyton-Ann. Rei. Bot.* 40, 91–96.
- Hudina M., Stampar F. (2002) Effect of phosphorus and potassium foliar fertilization on fruit quality of pears, in: Tagliavini M. et al. (Eds.), *Proceedings of the international symposium on foliar nutrition of perennial fruit plants*, Acta Hort. 594, 487–493.
- Huskisson E., Maggini S., Ruf M. (2007) The role of vitamins and minerals in energy metabolism and well-being, *J. Int. Med. Res.* 35, 277–289.
- Ilin Z., Durovka M., Markovic V. (2002) Effect of irrigation and mineral nutrition on the quality of potato, in: Paroussi G., Voyiatzis D., Paroussis E. (Eds.), *Proceedings of the second balkan symposium on vegetables and potatoes*, Acta Hort. 579, 625–629.
- Iwane A., Bessho H. (2006) Factors affecting the variation of mineral components of apples part VI - Effects of sunlight on the mineral content of apple fruit, *J. Jpn Soc. Food Sci.* 53, 151–157.
- Kahn T. (2008) Hypernatraemia, *Nephrol. Dial. Transplant.* 23, 4080–4081.
- Keutgen A.J., Pawelzik E. (2008) Quality and nutritional value of strawberry fruit under long term salt stress, *Food Chem.* 107, 1413–1420.
- Killilea D.W., Maier J.A.M. (2008) A connection between magnesium deficiency and aging: New insights from cellular studies, *Magnesium Res.* 21, 77–82.
- Kirchmann H., Johnston A.E.J., Bergström L.F. (2002) Possibilities for reducing nitrate leaching from agricultural land, *Ambio* 31, 404–408.
- Ko E.A., Han J., Jung I.D., Park W.S. (2008) Physiological roles of K⁺ channels in vascular smooth muscle cells, *J. Smooth Muscle Res.* 44, 65–81.
- Komljenovic I., Markovic M., Todorovic J., Cvijovic M. (2006) Influences of fertilization by phosphorus on yield and nutritional status of maize in Potkozarje area, *Cereal Res. Commun.* 34, 549–552.
- Kräutler B. (2005) Vitamin B12: Chemistry and biochemistry, *Biochem. Soc. Trans.* 33, 806–810.
- Lachance P.A. (1998) International perspective: Basis, need, and application of recommended dietary allowances, *Nutr. Rev.* 56, S2–S4.
- Lal R. (2009) Soils and food sufficiency. A review, *Agron. Sustain. Dev.* 29, 113–133.
- Lambert I.H., Hoffmann E.K., Pedersen S.F. (2008) Cell volume regulation: Physiology and pathophysiology, *Acta Physiol.* 194, 255–282.
- Lockett C.T., Calvert C.C., Grivetti L.E. (2000) Energy and micronutrient composition of dietary and medicinal wild plants consumed during drought. Study of rural Fulani, Northeastern Nigeria, *Int. J. Food Sci. Nutr.* 51, 195–208.
- Lopez M.V., Satti S.M.E. (1996) Calcium and potassium-enhanced growth and yield of tomato under sodium chloride stress, *Plant Sci.* 114, 19–27.
- Lopez-Berenguer C., Martinez-Ballesta M.C., Moreno D.A., Carvajal M., Garcia-Viguera C. (2009) Growing hardier crops for better health: Salinity tolerance and the nutritional value of broccoli, *J. Agr. Food Chem.* 57, 572–578.
- Losak T., Hlusek J., Kra S., Varga L. (2008) The effect of nitrogen and sulphur fertilization on yield and quality of kohlrabi (*Brassica oleracea*), *R. Bras. Ci. Solo.* 32, 697–703.
- Lukaski H.C. (2004) Vitamin and mineral status: Effects on physical performance, *Nutrition* 20, 632–644.
- Mäder P., Fliessbach A., Dubois D., Gunst L., Fried P., Niggli U. (2002) Soil fertility and biodiversity in organic farming, *Science* 296, 1694–1697.
- Mahouachi J. (2007) Growth and mineral nutrient content of developing fruit on banana plants (*Musa acuminata* AAA, 'Grand Nain') subjected to water stress and recovery, *J. Hortic. Sci. Biotech.* 82, 839–844.
- Malmauret L., Parent-Massin D., Hardy J.L., Verger P. (2002) Contaminants in organic and conventional foodstuffs in France, *Food Addit. Contam.* 19, 524–532.
- Maqueda C., Ruiz J.C., Morillo E., Herencia J.F. (2001) Effect of an organic amendment on nutrient availability and plant content, 11th Int. Symp. Environmental Pollution and its Impact on Life in the Mediterranean Region, MESAEP & SECOTOX, Proceedings Limasol (Chipre).
- Maynard D.N., Barker A.V., Minotti P.L., Peck N.H. (1976) Nitrate accumulation in vegetables, *Adv. Agron.* 28, 71–118.
- Mertz W. (1981) The scientific and practical importance of trace elements, *Philos. T. Roy. Soc. B* 294, 9–18.
- Moe S.M. (2008) Disorders involving calcium, phosphorus, and magnesium, *Prim. Care, Clinics in Office Practice* 35, 215–237.
- Montanaro G., Dichio B., Xiloyannis C., Celano G. (2006) Light influences transpiration and calcium accumulation in fruit of kiwifruit plants (*Actinidia deliciosa* var. *deliciosa*), *Plant Sci.* 170, 520–527.
- Moreno D.A., Villora G., Romero L. (2003) Variations in fruit micronutrient contents associated with fertilization of cucumber with macronutrients, *Sci. Hortic.* 97, 121–127.

- Morgan K.T. (2008) Nutritional determinants of bone health, *J. Nutr. Elder.* 27, 3–27.
- Narasinga Rao B.S. (2003) Anaemia and micronutrient deficiency, *Natl. Med. J. India* 16, 46–50.
- Neeser C., Savidov N., Driedger D. (2007) Production of hydroponically grown calcium fortified lettuce, *Proceedings of the 1st International Symposium on Human Health Effects of Fruits and Vegetable, Acta Hort.* 744, 317–321.
- Otero V., Barreal M.E., Merino A., Gallego P.P. (2007) Calcium fertilization in a kiwifruit orchard, *Proceedings of the 6th international symposium on kiwifruit, Vols 1 and 2, Acta Hort.* 753, 515–520.
- Pele L.C., Thoree V., Mustafa F., He S., Tsaprouni L., Punchard N.A., Thompson R.P.H., Evans S.M., Powell J.J. (2007) Low dietary calcium levels modulate mucosal caspase expression and increase disease activity in mice with dextran sulfate sodium-induced colitis, *J. Nutr.* 137, 2475–2480.
- Peters U., Chatterjee N., McGlynn K.A., Schoen R.E., Church T.R., Bresalier R.S., Gaudet M.M., Flood A., Schatzkin A., Hayes R.B. (2004) Calcium intake and colorectal adenoma in a US colorectal cancer early detection program, *Am. J. Clin. Nutr.* 80, 1358–1365.
- Ramirez-Serrano R., Larrinaga-Mayoral J.A., Murillo-Amador B., Hernandez-Saavedra N.Y., Fujiyama H. (2008) Antioxidant enzymatic response of hot pepper (*Capsicum annuum* L.) under saline stress conditions, *Interciencia* 33, 377–383.
- Rayssiguier Y., Gueux E., Nowacki W., Rock E., Mazur A. (2006) High fructose consumption combined with low dietary magnesium intake may increase the incidence of the metabolic syndrome by inducing inflammation, *Magnesium Res.* 19, 237–243.
- Recommended dietary allowance, Year of estimate, 2009, Available in: <http://www.anyvitamins.com/rda.htm>.
- Renkema K.Y., Alexander R.T., Bindels R.J., Hoenderop J.G. (2008) Calcium and phosphate homeostasis: Concerted interplay of new regulators, *Ann. Med.* 40, 82–91.
- Ríos J.J., Blasco B., Cervilla L.M., Rubio-Wilhelmi M.M., Ruiz J.M., Romero L. (2008) Regulation of sulphur assimilation in lettuce plants in the presence of selenium, *Plant Growth Regul.* 56, 43–51.
- Roe E. (1998) Compost utilization for vegetable and fruit crops, *Hortscience* 33, 934–937.
- Rosenthal J.J.C., Gilly W.F. (2003) Identified ion channels in the squid nervous system, *Neurosignals* 12, 126–141.
- Rouphael Y., Cardarelli M.T., Colla G. (2008) Yield, mineral composition, water relations and water use efficiency of grafted mini-watermelon plants under deficit irrigation, *Hortscience* 43, 730–736.
- Roychowdhury T., Tokunaga H., Ando M. (2003) Survey of arsenic and other heavy metals in food composites and drinking water and estimation of dietary intake by the villagers from an arsenic-affected area of West Bengal, India, *Sci. Total Environ.* 308, 15–35.
- Santamaria P., Elia A., Serio F., Todaro E. (1999) A survey of nitrate and oxalate content in retail fresh vegetables, *J. Sci. Food Agr.* 79, 1882–1888.
- Saure M.C. (2001) Blossom-end rot of tomato (*Lycopersicon esculentum* Mill) – a calcium – or a stress-related disorder? *Sci. Hortic.* 90, 193–208.
- Schwartz G. (2005) Molybdenum cofactor biosynthesis and deficiency, *Cell. Mol. Life Sci.* 62, 2792–2810.
- Schwarz J.R., Bauer C.K. (2004) Functions of erg K⁺ channels in excitable cells, *J. Cell. Mol. Med.* 8, 22–30.
- Sharpley A. N., Meisinger J. J., Power J. F., Suarez D. L. (1992) Root extraction of nutrients associated with long-term soil management, *Adv. Soil Sci.* 19, 151–217.
- Shenkin A. (2008) Basics in clinical nutrition: Physiological function and deficiency states of trace elements, *e-SPEN* 3, 255–258.
- Smith D.M., McKenna K., Thompson C.J. (2000) Hyponatraemia, *Clin. Endocrinol.* 52, 667–678.
- Sobotka L., Allison S., Stanga Z. (2008) Basics in clinical nutrition: Water and electrolytes in health and disease, *e-SPEN* 3, 259–266.
- Soupart A., Decaux G. (1996) Therapeutic recommendations for management of severe hyponatremia: Current concepts on pathogenesis and prevention of neurologic complications, *Clin. Nephrol.* 46, 149–169.
- Sritharan R., Lenz F. (1992) Effect of light regime on growth, carbohydrates and nitrate concentration in kohlrabi (*Brassica oleracea* var. gongyolodes L.), *J. Appl. Bot.* 66, 130–134.
- Starck Z., Siwiec A., Chotuj D. (1994) Distribution of calcium in tomato plants in response to heat stress and plant growth regulators, *Plant Soil* 167, 143–148.
- Staugaitis G., Viskelis P., Venskutonis P.R. (2008) Optimization of application of nitrogen fertilizers to increase the yield and improve the quality of Chinese cabbage heads, *Acta Agr. Scand. B-S.* P. 58, 176–181.
- Steingröver E., Ratering P., Siesling J. (1986) Daily changes in uptake, reduction and storage of nitrate in spinach grown at low light intensity, *Physiol. Plant.* 66, 550–556.
- Szefer P., Grembecka M. (2007) Mineral components in food crops, beverages, luxury food, species, and dietary food, in: Szefer P., Nriagu J.O. (Eds.), *Chemical and functional properties of food components series*, CRC Press, Taylor and Francis Group, New York, USA, pp. 231–322.
- Theobald H. (2005) Dietary calcium and health, *Nutr. Bull.* 30, 237–277.
- Thomas V.L.K., Gropper S.S. (1996) Effect of chromium nicotinic acid supplementation on selected cardiovascular disease risk factors, *Biol. Trace Elem. Res.* 55, 297–305.
- Togay Y., Togay N., Erman M., Dogan Y. (2008) Performance of dry bean (*Phaseolus vulgaris*) as influenced by phosphorus and sulphur fertilization, *Indian J. Agr. Sci.* 78, 299–303.
- Tomala K., Dilley D.R. (1990) Some factors influencing the calcium level in apple fruits, *Acta Hort.* 274, 481–487.
- Tromp J. (1975) The effect of temperature on growth and mineral nutrition of fruits of apple, with special reference to calcium, *Physiol. Plant.* 33, 87–93.
- Turan M., Kordali S., Zengin H., Dursun A., Sezen Y. (2003) Macro and micro mineral content of some wild edible leaves consumed in eastern anatolia, *Acta Agr. Scand. B* 53, 129–137.
- Turner N.C. (2001) Optimizing water use, in: Nösberger J., Geiger H.H., Struik P.C. (Eds.), *Crop science, progress and prospects, Third International Crop Science Congress, Hambourg, CABI, Wallingford, UK*, pp. 119–135.
- Unal G., Akalin A.S., Akbulut N. (2007) Importance of dairy products in metabolic syndrome-obesity and hypercholesterolemia - Part 1, *Agro. Food Ind. Hi. Tec.* 18, 26–28.
- Val J., Monge E., Risco D., Blanco A. (2008) Effect of pre-harvest calcium sprays on calcium concentrations in the skin and flesh of apples, *J. Plant Nutr.* 31, 1889–1905.
- Vidal-Martinez J.L., Nunez-Escobar R., Lazcano-Ferrat I., Etchevers-Barra J.D., Carrillo-Gonzalez R. (2006) Potassium nutrition of broccoli (*Brassica oleracea*) with conventional management and fertigation in a vertisol in greenhouse, *Agrociencia* 40, 1–11.
- Víllora G., Moreno D.A., Pulgar G., Romero L. (1999) Zucchini growth, yield, and fruit quality in response to sodium chloride stress, *J. Plant Nutr.* 22, 855–861.

- Villora G., Moreno D.A., Pulgar G., Romero L. (2000) Yield improvement in zucchini under salt stress: determining micronutrient balance, *Sci. Hortic.* 86, 175–183.
- Vogtmann H., Matthies K., Kehres B., Meier-Ploeger A. (1993) Enhanced food quality: Effects of compost on the quality of plant foods, *Compost Sci. Util.* 1, 82–100.
- Wang Z., Li S. (2004) Effects of N and P fertilization on plant growth and nitrate accumulation in vegetables, *J. Plant. Nutr.* 27, 539–556.
- Wang Z., Li S., Malhi S. (2008) Effects of fertilization and other agroeconomic measures on nutritional quality of crops, *J. Sci. Food Agr.* 88, 7–23.
- Wang Z., Tian X., Li S. (2001) The cause of nitrate accumulation in leafy vegetables, *Acta Ecol. Sin.* 21, 1136–1141.
- Warman P.R. (2005) Soil fertility, yield and nutrient contents of vegetable crops after 12 years of compost or fertilizer amendments, *Biol. Agric. Hortic.* 23, 85–96.
- Warman P.R., Havard K.A. (1997) Yield, vitamin and mineral contents of organically and conventionally grown carrots and cabbage, *Agr. Ecosyst. Environ.* 61, 155–162.
- Warman P.R., Havard K.A. (1998) Yield, vitamin and mineral contents of organically and conventionally grown potatoes and sweet corn, *Agr. Ecosyst. Environ.* 68, 207–216.
- Welch R.M., Graham R.D. (2004) Breeding for micronutrients in staple food crops from a human nutrition perspective, *J. Exp. Bot.* 55, 353–364.
- Welch R.M., Combs G.F. Jr., Duxbury J.M. (1997) Toward a 'green' revolution, *Issues Sci. Technol.* 14, 50–58.
- Williams C.M. (2002) Nutritional quality of organic food: Shades of grey or shades of green? *Proc. Nutr. Soc.* 61, 19–24.
- Williams F.H. (2008) Neuromuscular complications of nutritional deficiencies, *Phys. Med. Rehabil. Clin. N. Am.* 19, 125–148.
- Winter C.K., Davis S.F. (2006) Organic foods, *J. Food Sci.* 71, R117–R124.
- Wojcik P., Wojcik M. (2003) Effects of boron fertilization on 'Conference' pear tree vigor, nutrition, and fruit yield and storability, *Plant Soil* 256 413–421.
- Wopereis M.C.S., Tamélokpo A., Ezui K., Gnagnépou D., Fofana B., Breman H. (2006) Mineral fertilizer management of maize on farmer fields differing in organic inputs in the West African savanna, *Field Crop. Res.* 96, 355–362.
- Wszelaki A.L., Delwiche J.F., Walker S.D., Liggett R.E., Scheerens J.C., Kleinhenz M.D. (2005) Sensory quality and mineral and glycoalkaloid concentrations in organically and conventionally grown redskin potatoes (*Solanum tuberosum*), *J. Sci. Food Agr.* 85, 720–726.
- Xiao-Yun S., Guo-Zhen D., Hong L. (2006) Studies of a naturally occurring molybdenum-induced copper deficiency in the yak, *Vet. J.* 171, 352–357.
- Zhang F.C., Kang S.Z., Li F.S., Zhang J.H. (2007) Growth and major nutrient concentrations in *brassica campestris* supplied with different $\text{NH}_4^+/\text{NO}_3^-$ Ratios, *J. Integr. Plant Biol.* 49, 455–462.
- Zhou Y., Ren S., Wang Z. (1989) The effect of application of N fertilizer on the accumulation of nitrate in vegetables, *Acta Agr. Boreali-Sin.* 4, 110–115.
- Zhou Z.Y., Wang M.J., Wang J.S. (2000) Nitrate and nitrite contamination in vegetables in China, *Food Rev. Int.* 16, 61–76.
- Zimmermann M.B., Köhrle J. (2002) The impact of iron and selenium deficiencies on iodine and thyroid metabolism: Biochemistry and relevance to public health, *Thyroid* 12, 867–878.