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# Agronomic biofortification with selenium in sweet potato

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## ABSTRACT

Selenium (Se) is an essential nutrient for the functions of the human body, and lacking in a large part of the population, and can be incorporated into human nutrition via agricultural products. However, the concentration of Se in agricultural products consumed in Brazil is considered low in relation to international standards. With the purpose of producing more nutritionally complete and healthy foods for human consumption, biofortification is an effective and safe technique in agricultural crops. The present literature review aims to address the topic of agronomic biofortification, highlighting the importance of Se in human health and its functions in vegetables, and of sweet potato as an essential agricultural crop to ensure food security.

**Keywords:** Agronomic biofortification, Ipomoea batatas (L.) Lam, Human nutrition, Selenium.

## 1 INTRODUCTION

In the context of food security, sweet potatoes stand out among the world's staple food crops (LEBOT, 2020), where they play an important role in the internal food supply and as a nutritional complement in the population's diet (LAURIE *et al*., 2013). The cultivation of sweet potatoes is important in different aspects, both economic, nutritional, and social. However, the crop is still considered subsistence, where its majority production comes from family farming (LIMA *et al.,* 2018). Despite its importance to the country, the culture is still little explored in the scientific community. Many agronomic recommendations come from other tuberous vegetables, in addition to the lack of phytosanitary products registered for the crop (MELLO, 2015).

The micronutrient selenium (Se), in turn, is considered an essential mineral element for human health, acting in the constitution of important proteins and enzymes, with different physiological functions, antioxidative (WONG *et al., 2010), anticancer (TARA et al*., 2010), and *immunity stimulants (RAMOUTAR and BRUMAGHIM, 2010*). Despite the need and importance of this element in the human diet, the *World Health Organization* (WHO) estimates that 15% of the world's population is deficient. To reduce this deficiency in susceptible regions, crop development using biofortification interventions has been undertaken in several countries, such as Finland, the United Kingdom, New Zealand, Malawi, parts of China, Tibet, and Brazil (ALFTHAN *et al*., 2015; BROADLEY *et al*., 2006; REIS *et al*., 2017; WU *et al*., 2015).

Biofortification is an innovative and efficient technique in agricultural crops, representing an effective and safe means of agricultural intervention, with the objective of improving the nutritional quality of food. Biofortification can be implemented via genetic improvement or by agronomic means via plant fertilization. In agronomic biofortification, the nutritional supply is carried out via soil or foliar, thus providing the enrichment of vegetable crops.

Brazil is in evidence in the development of projects in the area of biofortification. The **BioFORT Network**, coordinated by Embrapa, is the set of national projects responsible for food biofortification, aiming to reduce malnutrition and ensure greater food security. The country is the only one where work with eight different crops is coordinated concomitantly, namely, pumpkin, rice, sweet potato, beans, cowpea, cassava, corn and wheat (ROCHA, 2014). To date, three cassava cultivars with higher levels of provitamin A, two cowpea cultivars with high levels of iron and zinc, and a variety of sweet potato with high content of provitamin A have been developed.

Agencies such as WHO, FAO (Food and Agriculture Organization of the United Nations) and UNICEF (United Nations Children's Fund) suggest that in order to combat hidden hunger and malnutrition, it is necessary to implement intervention programs aimed at food fortification.

## 2 SWEET POTATO

Sweet potato (*Ipomoea batatas* (L.) Lam.) It has received prominence in recent years due to its important socioeconomic role, being considered one of the highest value food crops in the tropics. Different studies list sweet potatoes as a crop with high energy, vitamin and mineral value. Due to its high nutritional composition, it is considered a food crop with the potential to reduce nutritional deficiencies in population portions lacking in calories or nutrients, (KEHOE *et al*., 2015).

Sweet potato is a perennial crop, classified as tuberous root, originated in tropical America, and has great potential in agriculture, due to its ease of adaptation to different climatic conditions, and its low-cost cultivation (SOARES, 2013). Sweet potato is one of the main tuberous crops produced on a global scale, mainly in tropical and temperate regions of Africa, America and Asia. FAO statistics (2019) point to China as the world's largest producer, with 71.7 million tons. More than 97% of the world's sweet potato production comes from developing countries, where it plays a vital role in the domestic food supply and as a nutritional supplement in the diet of its population (LAURIE *et al*., 2013).

In 2019, the total national production of sweet potatoes was 805,412 thousand tons in 57,486 planted hectares (IBGE, 2019). Data from the Institute of Agricultural Economics (IEA) show that the state of São Paulo produced 147,959 tons of sweet potatoes in 2019, which represents about 20% of the national production, with the main producing regions being Presidente Prudente, Araçatuba, Tupã, Jaboticabal and Dracena (IEA, 2019).

The development cycle of sweet potatoes consists of three phases: the initial phase, where the growth of the adventitious roots occurs; the intermediate phase in which the beginning of tuberization occurs; and the final phase, established by the accumulation of photoassimilates in the tuberous roots (QUEIROGA *et al.*, 2007). The beginning of tuberization occurs with the expansion of the diameter of the adventitious roots (MEDEIROS *et al.*, 1990).

Environmental conditions such as temperature and solar radiation are determining factors in the formation of tuberous roots. High or low temperatures delay or prevent the onset of tuberization (VILLORDON *et al.*, 2009). The ideal temperature for tuberous root growth is around 25°C (SPENCE and HUMPHRIES, 1972; VILLAVICENCIO *et al.*, 2007; RAVI *et al.*, 2009).

The most striking characteristics of this crop are its hardiness, ease of cultivation, resistance to drought and wide capacity to adapt to different edaphoclimatic conditions (CARDOSO *et al.*, 2007). Its response to fertilization depends on the soil conditions in which it is grown. It should be well drained, with a medium and sandy texture, with a pH between 4.5 and 7.7 (PERESSIN and FELTRAN, 2014). When cultivated in soils of medium to high fertility, it usually does not manifest results in fertilization. However, in less fertile soils, the use of fertilizers promotes an increase in productivity, according to Monteiro and Peressin (1997), and Echer *et al.* (2009).

The water requirement of the crop is around 500 to 750 mm of water depth during the production cycle (EMBRAPA, 1995; SOARES *et al.*, 2002). On the other hand, the macromineral requirements of the crop follow the following descending order, as described by FAO (2006): potassium (K), nitrogen (N), phosphorus (P), calcium (Ca) and magnesium (Mg).

For most tuberous vegetables, K is the most demanded mineral nutrient. Sweet potato crops have shown high responses to potassium fertilization (FILGUEIRA, 2003). K acts in the processes of cell division, initiation of the tuberous root and its thickening, translocation of carbohydrates in the plant, among other functions (MARSCHNER, 1995). According to Corrêa *et al.* (2016), K also improves water use efficiency, intensifies nitrogen fertilization and enhances photosynthesis and cellular respiration (MARSCHNER, 1995).

However, the application of high K doses can impair plant development, due to the increase in saline concentration, or through leaching losses, and fertilization should be recommended according to soil analysis. Potassium chloride (KCl) is the most widely used source of potassium fertilization (NASCIMENTO, 2013; LOPES, 1998). According to Monteiro and Peressin (1997), the recommendations for the state of São Paulo follow Bulletin 100, where 60 kg ha-1 of K is applied at planting and 90-120 kg ha-1 at topdressing, after 45 days of planting. The splitting of K is due to the fact that it is a soluble and very mobile element in the soil.

N, in turn, is the second most required nutrient by vegetables (FILGUEIRA, 2003). According to Filgueira (2008), the production response of sweet potato crop associated with N is low and may vary. Nitrogen fertilization should be judicious, especially if the soil is rich in organic matter, as it causes exaggerated vegetative growth, to the detriment of the formation and development of potatoes that have a lower sugar content. However, N deficiency hinders plant development, causing reduced photosynthesis, yellowing and drop of basal leaves (SILVA *et al*., 2008). Monteiro and Peressin (1997) recommend for the state of São Paulo the application of 20 kg ha-1 of N at planting and 30 kg ha-1 of topdressing after 45 days of planting.

Sweet potatoes have a branched root system, being highly efficient in absorbing nutrients, such as P, for example. However, due to the deficiency of this nutrient in Brazilian soils, there is a need to apply readily available P at planting (EMBRAPA, 1995). The recommendations are 80 100 kg.ha-1 of the mineral at planting. Adequate phosphate fertilization is essential from the early stages of plant growth, and the provision of adequate P dosages allows root development and increased water and nutrient absorption (CAI *et al*., 2013). P is important in the processes of respiration and cell division, as well as in energy production. The nutrient can be readily mobilized in plants, and in cases of nutritional deficiency, it is translocated from older tissues to active meristematic regions (HERMANS *et al*., 2006).

Macronutrients such as Ca and Mg are usually supplied by liming, when necessary. Regarding micronutrients, such as boron (B), the main source of micronutrients is organic matter (ABREU *et al*., 2007). Thus, soils with a high content of organic matter do not need to use fertilization via fertilizers to supply this micronutrient.

Sweet potatoes are an important source of nutrients and can be used to improve diets, especially in developing countries. It has a high content of vitamin A, B vitamins and minerals such as calcium, sulfur, iron, magnesium and potassium (LOW *et al*., 2007). It is a food with a high energy value, having about 30% of dry matter, which comprises an average of 85% of carbohydrates, whose main element is starch (CARDOSO *et al*. 2007). Per 100 grams, sweet potatoes provide, on average, the following mineral contents: K (273 mg), P (49 mg), Ca (30 mg), S (26 mg), Mg (24 mg), and Na (13 mg) (MIRANDA *et al*., 1987; SILVA, 2002; SOARES *et al*., 2002;).

Different institutions around the world encourage the consumption of sweet potato tuberous roots by populations that manifest a history of diseases linked to malnutrition, especially in emerging countries (LEITE, 2017).

## 3 AGRONOMIC BIOFORTIFICATION

Agronomic biofortification is a sustainable agricultural strategy, which consists of the nutritious enrichment of foods with higher population consumption. The practice of agronomic biofortification consists of increasing the concentration of one or more micronutrients during cultivation by means of soil or foliar fertilization (GRAHAM *et al*., 2007). The goal is for these nutrients to be absorbed and accumulated by the plants, aiming at an improvement in food and human health. The biofortification technique consists of the assumption that the levels of minerals present in the crops are associated with their availability in the environment (DURÁN *et al*., 2013).

Biofortification is the focus of the Harvest Plus program of CGIAR *(Consultive Group on International Agriculture Research*), an international program responsible for organizing and encouraging food biofortification actions in the world (JONS and EYZAGUIRRE, 2007). The program symbolizes a strong and important form of intervention to increase the intake of essential nutrients through base crops, such as rice, pumpkin, sweet potatoes, beans, cassava, corn and wheat (NUTTI, 2011).

In Brazil, in 2003, Embrapa developed the project "Biofortification of Agricultural Products for Human Nutrition - HarvestPlus", the main component of the HarvestPlus *Challenge Program* in Brazil. The aim of the project is to contribute to the reduction of malnutrition in the poorest spheres of the populations of emerging countries, in a feasible way, since the food crops contemplated in the program already have wide production, acceptance and consumption in Brazil (NUTTI, 2011).

According to Nutti (2011), Brazil is the only country that manages breeding work with eight basic crops simultaneously, namely: pumpkin, rice, sweet potato, beans, cowpea, cassava, corn and wheat, making the research and development of biofortified foods in Brazil stand out and differentiate itself from other countries.

Agronomic biofortification was shown to be efficient in a study carried out by Zhang *et al*. (2019), which tested the foliar application of two sources of selenium in potato crops, and proved the efficiency to improve the concentration of total Se in potatoes. Different forms of application and sources of Se were evaluated in the biofortification of carrots, where Oliveira *et al*. (2018) showed an increase in the Se content of the vegetable.

In a different study, Smolén *et al*. (2018) found, after a three-year field trial, that biofortification combined with Se and iodine (I) in carrot cultivation is a viable technique. All cultivars evaluated accumulated both elements at a substantially higher level than the control plants, with no adverse effect on other nutritional characteristics of the crop.

Evaluating Se in the physiological performance and agronomic biofortification of cauliflower, Dutra (2017) found that selenate provided greater efficiency of absorption and translocation of Se in the plant, providing high concentrations of the element in plant tissue.

Plants are at the beginning of the entire food chain. Therefore, by improving the uptake of minerals from the soil and increasing their translocation and bioavailability in the edible parts of plants, it is possible to provide benefits for human, and consequently animal, nutrition (EL-RAMADY *et al*., 2014).

## 3.1 SELENIUM IN PLANTS

Selenium (Se) is an essential trace element for most forms of life. The element has received prominence in recent years, being a source of studies and research in several countries, due to its importance in food and its essentiality in the human body (WHITE, 2016). Although it has not been confirmed as an essential nutrient in vegetables, there is growing evidence that Se is a beneficial element for plants, as an antioxidant and promoter of plant growth.

Several studies have shown that, at low concentrations, Se exerts a beneficial effect on plant growth and tolerance to environmental stresses (PILON-SMITS *et al.*, 2009; DIAO *et al.*, 2014; MALAGOLI *et al.*, 2015). Recent studies have shown that the supply of Se to plants promotes multiple benefits (SIEPRAWSKA *et al.*, 2015). These studies point to a greater influence of Se on the antioxidant system and nitrogen and carbohydrate metabolisms (NAWAZ *et al.*, 2015).

Selenium plays a vital role as a protector against different abiotic stresses, cooling, submersion, drought, and nutrient deficiency (HUSSAIN *et al.*, 2016a, b; KHAN *et al.*, 2018). Possible mechanisms involved in abiotic stress tolerance in plants may involve: antagonism (in the case of heavy metals), detoxification of deleterious organic compounds, free amino acids, enhanced antioxidant defense system, protection of membranes and important biomolecules from physiological stress damage, and improved growth and biomass production through increased photosynthetic activity, chlorophyll content, and regulation of transpiration rate (FAHIM *et al.*, 2013; FENG *et al.*, 2013; YAO *et al.*, 2013; KHALIQ *et al.*, 2015; SHARMA *et al.*, 2017; KHAN *et al.*, 2018).

The mobility, bioavailability and absorption of Se by plants are influenced by two important factors, pH and soil organic matter (PILON-SMITH and LEDUC, 2009). It can be inferred that, with the decrease in pH, the uptake and adsorption of Se sources increase, leading to low mobility of the mineral in the soil, while the increase in pH increases its mobility (EICH-GREATOREX *et al.*, 2007). Organic matter, when present at high content, leads to lower Se mobility. However, the mechanisms that govern the interaction between selenium and soil organic matter are not evident (BRUGGEMAN *et al.*, 2007).

Selenium exists as both inorganic and organic forms in nature. The inorganic forms are selenate (SeO2-4), $^{\text{selenite (SeO2-3}}$), selenide ($^{\text{Se-2}}$) and Elemental Se. The main organic forms are selenocysteine (SeCys) and selenomethionine (SeMet) (BODNAR *et al.*, 2012; WU *et al.*, 2015). The inorganic forms of Se salts, sodium selenate (Na2SeO4) and sodium selenite (Na2SeO3), are those that plants have the ability to absorb from the soil and convert into the organic form of SeMet and SeCys, which can be incorporated into proteins (DANIELS, 1996). It is important to note, however, that the threshold between benefit and toxicity of Se in vegetables can be modified depending on the source and concentration of this element.

Sodium selenate is the most prevalent form of bioavailable Se in agricultural soils, being the most mobile and soluble form, while selenite is more present in acidic soils (MISSANA *et al.*, 2009; GUPTA and GUPTA, 2017). Both forms of Se differ in terms of mobility and uptake within the plant, and are metabolized to form selenocompounds (LI *et al.*, 2008). There are marked differences in the absorption, translocation and metabolism of Se when it comes from different sources (LONGCHAMP *et al.*, 2015).

Selenate is absorbed by the roots through sulfate transporters (CABANNES *et al.*, 2011; GUPTA and GUPTA, 2017), while selenite is taken up by the roots via phosphate transporters (WINKEL *et al.*, 2015). Selenate has sulfur-like chemical properties (S) (NAZ *et al.*, 2015; GOLOB *et al., 2016), so both elements share a metabolic pathway in common by plants during the translocation process (SORS* et al., 2005). Once absorbed by plant roots, selenate is immediately translocated to the aerial part through the symplastic pathway (WHITE  et al., 2004*), which is the dominant form of xylem-driven Se (LI et al., 2008).*

Se is transported via xylem to the cell plastids of the leaves, where ATP-sulfurilase (APS) initiates the assimilation of the element with the transformation of selenate into adenosine phosphoroselenate (APSe), which then undergoes a process of reduction to selenite by the action of the enzyme adenosine phosphoroselenate reductase (APR). Subsequently, selenite is transformed into selenide by sulfite reductase activity, and finally, selenite is converted into SeCys by the action of O-acetylserine (thiol)lyase (OAS-TL). SeCys is rapidly synthesized into other compounds and proteins. Unlike SeCys, the process of SeMet formation takes place in the cytosol, where it can be transformed into volatile Se compounds, or proteins. Selenite cannot yet be stated, but it is believed to be absorbed by the roots through phosphate transporters (WINKEL *et al.*, 2015; WAN *et al.*, 2016).

The high concentration of sulfate in the growth medium antagonizes Se and preferential absorption of sulfate over selenate occurs, while the higher concentration of sulfate in the tissue can stimulate Se selectivity by the same S transporters (WHITE *et al.*, 2004). Selenite, on the other hand, is assimilated into organic forms (SeCys and SeMet) at the root (WANG *et al.*, 2015; HUANG *et al.*, 2017).

Thus, selenate is a preferred source to be used in Se biofortification programs. The carriers responsible for loading the selenate into the xylem, however, are still unknown. It is important to note, however, that the threshold between benefit and toxicity of Se can be modified depending on the source and concentration of this element. In a biofortification program, Se rates should be carefully planned, due to their narrow boundary between benefit and toxicity on plant growth and production (SARWAR *et al.*, 2020).

## 3.2 SELENIUM IN HUMAN HEALTH

Selenium (Se) is an essential trace element in human metabolism, mainly because it acts in important metabolic functions (ÁVILA *et al.*, 2013; KAUR *et al.* 2014; SUPRIATIN *et al.*, 2015; MATOS  et al., 2017), playing a key role in important areas of health, such as the immune system, thyroid hormone metabolism, male infertility, neoplasms, and cardiovascular diseases (PORRAS *et al., 2010; USLU et al.*, 2010), in addition to also having antioxidant properties (COMINETTI, 2011).

Se acts as a component of several enzymes and proteins (ÁVILA *et al.*, 2013; KAUR *et al.* 2014). The importance of selenium in the body is due to the fact that it is a component of selenoproteins, which have important enzymatic functions. Thus, selenium ends up functioning as an important reducer, especially in the neutralization of free radicals (SUNDE, 1997; FAIRWEATHER-TAIT *et al.*, 2010). In humans, at least 25 selenoproteins play important roles in antioxidant systems, immunity, male fertility, resistance to viral infections, and the prevention of different types of cancer (HARTHILL, 2011; RAYMAN, 2012, 2020; TAN *et al.* 2018)

In 1979, it was found that Se supplementation is able to prevent the onset of Keshan disease, which affects children who live in soils deficient in this mineral (KESHAN, 1979). More recent studies have shown that Se deficiency can contribute to cognitive decline in older people, in addition to being associated with oxidative stress observed in patients with Alzheimer's and type 2 diabetes (CARDOSO *et al.*, 2010; RAYMAN, 2012). However, there is a narrow safety range between benefit and toxicity levels. A daily dose of 25–35 μg is recommended for adults, depending on age and gender (WHO, 2009).

It is suggested by Kipp *et al.* (2015) that the daily intake for adult women and men is 60-70 μg. This recommendation is in line with the values recommended by the nutrition societies of Germany, Austria and Switzerland. According to White (2016), the recommended daily intake is 55 μg for adults. On the other hand, Almondes *et al.* (2010) suggest that the use of a daily supplementation of 200 μg of Se may decrease the risk of cancer. In 2014, the CCNFSDU (Codex Committee on Nutrition and Food for Special Dietary Uses) agreed to establish a new reference value for Se, at 60 μg $^{\text{day-1}}$.

According to Combs (2001), there is a great variation in Se intake between different countries on different continents. It is estimated that 15% of the world's population is deficient in Se and the main cause is the low consumption of this nutrient (WHITE and BROADLEY, 2005). Considering that Se feeding is basically derived from food, Se deficiency in humans is related to the consumption of foods that are low in Se in the edible parts (REIS *et al.*, 2017).

## 4 CONCLUSIONS

Selenium deficiency in humans is linked to the quality of the diet and is aggravated by the deficiency of this micronutrient in the soil and, consequently, in plants, the main sources of selenium in the diet. The cultivation of energy crops such as sweet potatoes and their enrichment through agronomic biofortification is of the utmost importance, due to the characteristics of production and important role in food and nutritional security in developing and underdeveloped countries. Research on selenium biofortification in sweet potatoes needs to be expanded to better understand the conditions that affect selenium absorption and bioavailability and, thus, enable the definition of strategies to combat deficiencies of this important nutrient for plant physiology and human health.

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