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Nutriduo

Nourish plants. Benefit lives!

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Introduction

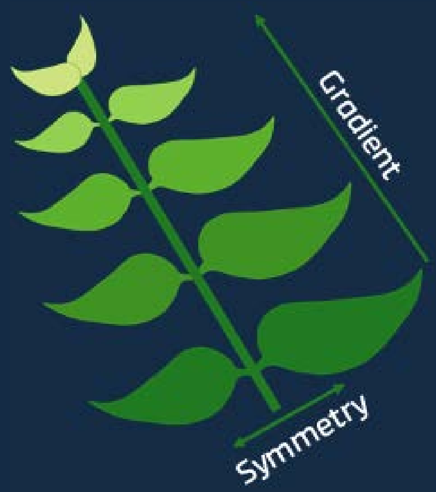
Tropical soils, especially in the Brazilian savannah, have low natural fertility, due to soil genesis and a high degree of weathering that occurs in these regions. Thus, low pH values, deficiencies of nutrients such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), borax (B) and zinc (Zn) sac) are frequently reported and limits the productivity of these areas (Lopes & Guilherme, 1994; Lopes et al., 2012). Thus, management that increases the content of these elements in the soil and consequently, the productivity of agricultural crops, is needed.

Plants, as sessile organisms, have undergone adjustments to adapt to the various conditions of the environment to which they are exposed, among the main types of stress to which they are subjected to, we mention heat, light, water and saline stress, among others (Barbosa et al., 2014; Taiz et al., 2017; Rosa et al., 2021). Regardless of the stress, there is always an increase in reactive oxygen species (ROS) that directly affect cell homeostasis, leading to apparent oxidative damage and, possibly, cell death (Mittler, 2002; Zhang et al. al., 2016; Rosa et al., 2021).

Nutritional deficiency is one of the main factors that greatly aggravate the damage caused by EROs in plants. However, it is known that well-nourished plants are able to better withstand adversities, whether biotic or abiotic (Malavolta, 2006; George et al., 2012; Taiz et al., 2017). Still within this scope, the literature is quite comprehensive and shows a response to the use of some elements, attenuating the most diverse types of stress in responses that range from stability and permeability of membranes to the activation of enzymes of the antioxidant system (Broadley et al., 2012A, Broadley et al., 2012B, Barbosa et al., 2014; Taiz et al., 2017; Lanza, 2021).

Did you know...

...that to be considered a symptom of nutritional deficiency, it must occur in general, in all plants present in the area, according to the color gradient and symmetry of the plant?



Still with regard to the Mineral Nutrition of Plants, it is important to point out that this is directly related to Human Health and, therefore, should not be analyzed separately. Many of the elements considered essential to humans and animals also play important roles in plant metabolism and, in many cases, their mechanisms of action are similar. On the other hand, the search for higher yields to satisfy global consumption caused the nutritional quality of the harvested product to decline, especially after the Green Revolution.

Therefore, the challenge agriculture now faces is to increase nutritional quality, targeting not only plants, but also human and animal nutrition, even more so when the central theme is food security (Souza, 2013). Thus, the objective of this bulletin is to gather more information on these topics and propose some solutions that will help in the metabolism, growth and development of plants and also present new concepts such as biofortification and food security that are still little used in Brazilian agriculture.

Did you know...

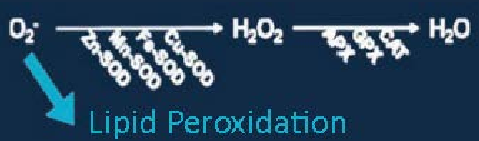
(Gupta et al., 2018)

...that EROs are produced in virtually all organelles, however, the main producing organelles are: chloroplasts, mitochondria and peroxisomes?

In chloroplasts, O_{2-} is produced in thylakoid membranes and in photosystem I

In peroxisomes, O_{2-} is produced in the cell matrix and membranes.

In mitochondria ,O_{2-} is formed mainly in the matrix and inner membrane.



Oxidative stress and elements that fight them in plant metabolism

Oxidative stress in plants

It is estimated that plants express only 24% of their productive potential and that 11% is lost as a result of biotic stress and that the remainder, i.e., 65% results from the abiotic stresses to which plants are subjected (Bray et al., 2000). However, it is believed that these losses can be minimized depending on the management adopted for the crops.

Among the main types of stress to which plants are subjected, we can mention: excess light radiation, water deficit, temperature extremes, salinity, heavy metals, attack by pests and diseases.

Oxidative stress is a common process of plant metabolism and is involved in almost all reactions, especially photosynthesis and respiration (Mittler, 2002). On the other hand, when there is excess in the formation of radicals, regardless of the causal agent, it is the elevation of free radicals that must be given attention.

Generally, at the slightest sign of abiotic stress, there is an increase in the formation of EROs in organelles related to the photosynthetic apparatus such as mitochondria, chloroplasts and peroxisomes (Mittler, 2002; Gupta et al., 2018). This happens because under conditions that induce plants to stress, the stomata close, limiting the absorption and fixation of CO_2. As examples, we can mention the water stress and light excess that, in general, occur simultaneously, where plants experiencing water deficit keep their stomata closed, but solar radiation does not stop entering, maintaining the light phase active (Figure 1A). On the other hand, with closed stomata, there is no energy conversion in ackars, as the biochemical phase is interrupted (Figure 1B) (Santaniello et al., 2017; Pereira et al., 2020).

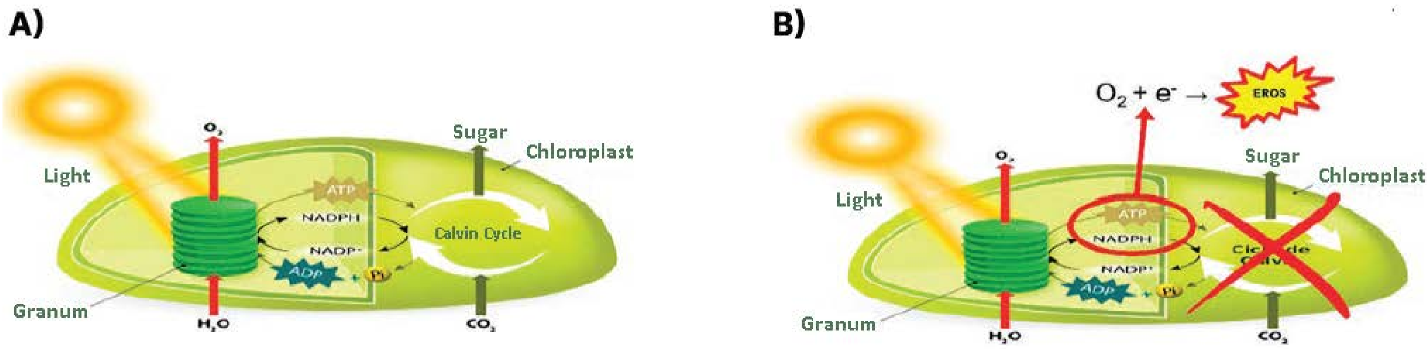


Figure 1. Stages of photosynthesis in chloroplasts up to the conversion of CO_2 to carbohydrates (A). However, when this conversion is interrupted, EROs are generated (B). Adapted from infoescola.com/biologia/fotossíntese.

With the Calvin Cycle paralyzed, there is an excess of electrons in the organelles of the photosynthetic apparatus leading to the production of EROs (Mittler, 2002; Taiz et al., 2017).

In response to this increase in EROs and in order to minimize the damage caused by these radicals to their tissues, plants have different defense pathways that can be enzymatic or non-enzymatic (Mittler, 2002; Barbosa et al., 2014; Gupta et al., 2018). Among the main enzymes of the enzymatic pathway, we can mention superoxide dismutase (SOD), catalase (CAT), peroxidases (POD), ascorbate peroxidase (APX) and polyphenoloxidase (PPO) (Barbosa et al., 2014; Gupta et al., 2018; Tavanti et al., 2021). As for the non-enzymatic mechanisms, ascorbate (AsA), glutathione (GSH), carotenoids and tocopherols have been highlighted (Barbosa et al., 2014; Gupta et al., 2018). It is worth noting that both enzymatic and non-enzymatic mechanisms aim to prevent damage caused by free radicals in plant cells.

Another point worth mentioning is that plants subjected to prolonged stress may not recover, as the damage to metabolism is irreversible (Gupta et al., 2018; Tavanti et al., 2021). As with nutritional deficiencies, when oxidative stress damage is visible, a sequence of abnormalities has already occurred, resulting in changes in leaf tissues (Figure 2).

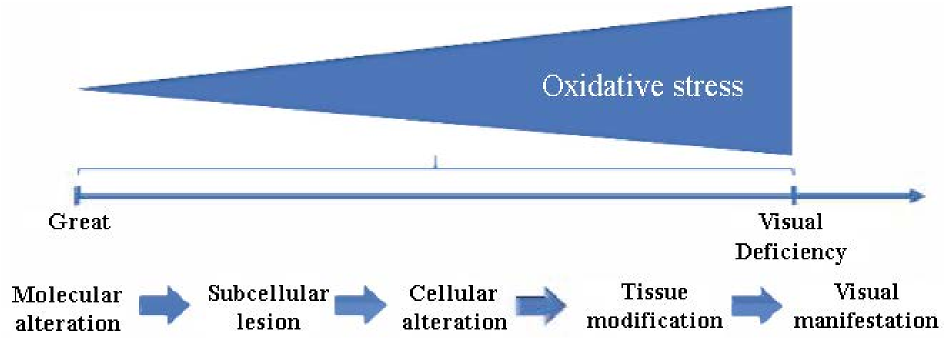


Figure 2. Sequence of oxidative stress abnormalities that culminate in visible manifestations in plants.

It is already known and widely explored that well-nourished and, consequently, balanced plants are able to tolerate adversity. However, it is a relatively new topic that the application of some elements, even at low concentrations, improve the responses of the plant antioxidant system, including attenuating damage caused by stress (Gupta et al., 2018; Tavanti et al., 2021). Some of the elements that have this potential will be listed below.

Selenium: dynamics in the soil-plant system and antioxidant metabolism

Selenium (Se) belongs to the group of chalcogens and, in soils, the contents are generally low, in the range of 0.05 and 1.5 mg kg^{-1}. However, seleniferous areas, where this element is exploited, may present concentrations above 1,200 mg kg^{-1} (Kabata-Pendias, 2011). Se contents are mainly related to the source material of the soil. However, other factors can influence the availability of this element in the soil, such as: organic matter content, redox potential, chemical form present, pH, soil texture and mineralogy (Broadley et al., 2012B; Qin, 2012; Jones et al., 2016).

Unlike the other elements, which are included in fertilizations, the Se increments in soils occur due to atmospheric deposition, mainly in coastal areas and with high volcanic activities, volatilization and burning of selenoferrous vegetation (Kabata-Pendias & Pendias, 2001). On the other hand, projections show that the Se levels in the soil tend to decrease due to some factors, such as: increases in yields, application of fertilizers without this element, competition with sulphate ions and factors such as precipitation, soil correction were also analyzed. (Figure 3) (Jones et al., 2016).

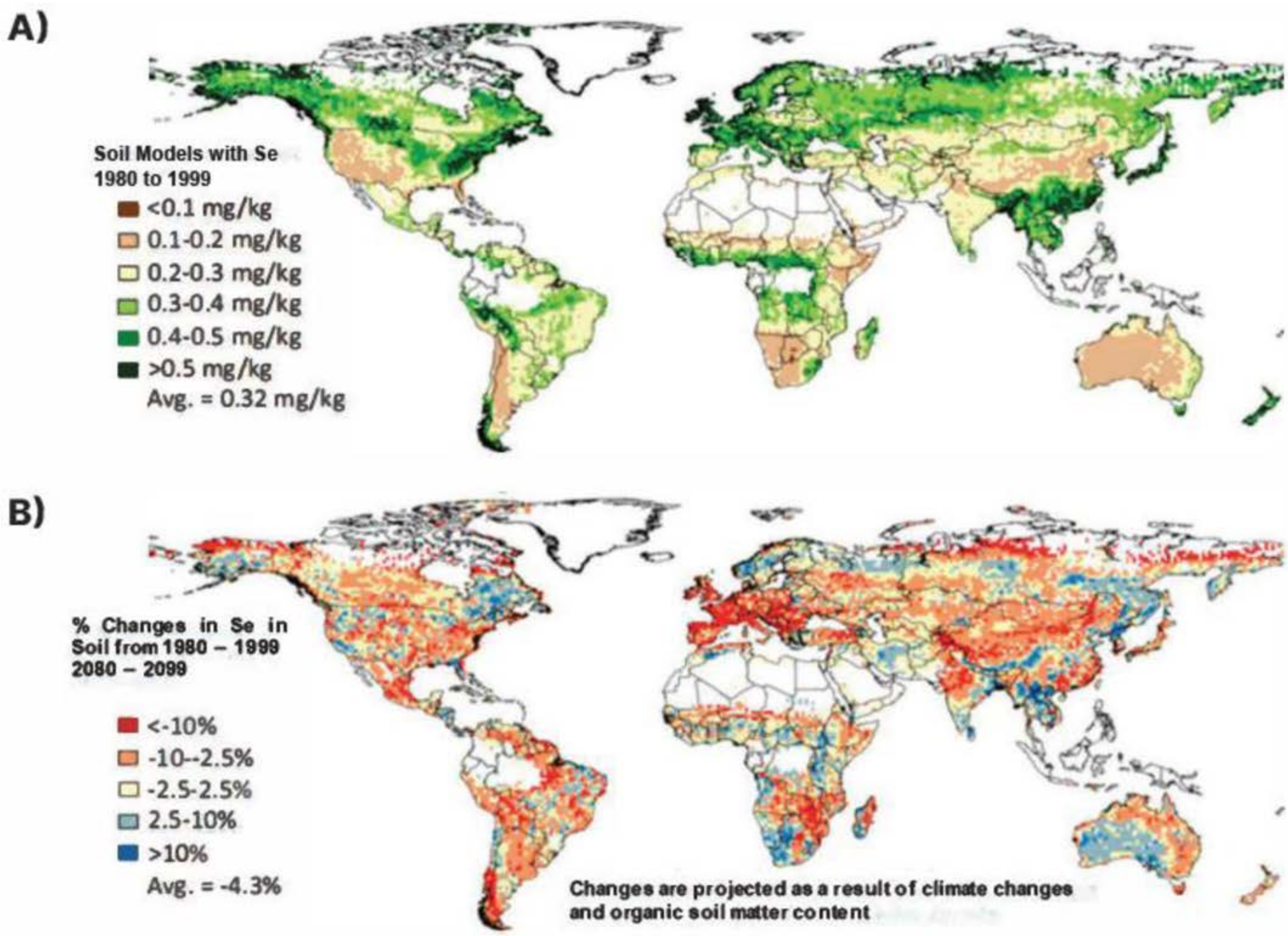


Figure 3. Geographic representation of prediction models in 1st scale. The model illustrates Se levels in the soil (1980 to 1999) (A) and the percentage change in soil Se levels between present and future (2080 to 2099) (B). For this, climate projections, evapotranspiration, were taken into account. Precipitation, soil organic matter, aluminum contents, clay % and pH. Adapted from Jones et al. (2016).

Naturally, Se is found in selenite (SeO_3^{2-}) and selenate (SeO_4^{2-}) forms. Selenite is adsorbed with greater affinity than selenate in soil particles, especially in low pH soils, in the presence of Fe oxide and organic matter (Broadley et al., 2012B). Thus, selenite has a lower bioavailability than selenate in soils. On the other hand, selenate is more soluble, mobile and easily available for plant absorption in neutral and alkaline soils (Kabata-Pendias, 2011; Broadley et al., 2012B). Se adsorption can be reduced through the application of phosphates and sulphates, especially in soils with high Fe and Mn contents (Kabata-Pendias, 2011; Kabata-Pendias & Pendias, 2001).

There are few reports in the literature on Se levels in Brazilian soils (Ferreira et al., 2002; Carvalho; 2011; Gabos, 2012). In soils of the Brazilian savannah Biome, under native vegetation, in the states of Minas Gerais and Goiás, it was found that the levels of Se, in two layers (0-20 cm and 80-100 cm) ranged from <22 to 81ug kg^{-1} (Carvalho, 2011). In the state of São Paulo, in the 0-20 cm layer, the levels ranged from <0.08 to 1.61 mg kg^{-1}, with the average being close to 0.19 mg kg^{-1} of Se (Gabos, 2012).

No different from what happens to the other elements, the Se present in the soil is what will determine its concentration in plant tissues and grains (Li et al., 2008A). In fact, for it to be absorbed by plants, factors such as the form of the element, the content of organic matter, soil pH, redox potential, ionic competition, moisture, temperature and soil texture have a direct influence on the absorption (Li et al., 2008A; Cubadda et al., 2010).

As they are recent studies involving the absorption of this element by plants, the mechanisms have not yet been fully elucidated. Studies show that selenite absorption occurs passively and, most likely, using phosphate ion transporters and that selenate absorption occurs actively and sulphate transporters are used in this process (Li et al., 2008B; Zhu et al., 20086; Zhu et al. al., 2009). Selenate is a form that presents less harmful aspects to crops than selenite, therefore, crops respond differently to fertilizations when these two sources are used (Li et al., 2008B; Zhu et al., 2009).

For plants, Se has not been proven essential, and is therefore reported as a beneficial element (Malavolta, 2006; Broadley et al., 2012B; Taiz et al., 2017). Recent studies show that at low concentrations, this element improves metabolic responses and increases antioxidant activity (Hernandez-Hernandez et al., 2019; Lanza, 2021; Mateus et al., 2021).

In general, these responses to improve the antioxidant system in the fight against EROs are associated with the formation of proteins that have Se in their composition, the so-called selenoproteins. These enzymes act as a strong catalyst in cellular metabolism through glutathione peroxidase (GSH) increasing the potential of enzymes such as SOD, CAT, APX and GPX (Gupta & Gupta, 2017; Hernandez-Hernandez et al., 2019; Lanza, 2021). The selenoproteins also act on the activity of non-enzymatic compounds such as phenols, ascorbic acid and flavonoids that are fundamental in the elimination of EROs by plants (Gupta & Gupta, 2017; Hernandez-Hernandez et al., 2019; Lanza, 2021).

Did you know...

(Faquin, 2005)

...that for plants, elements are considered as essential, beneficial or toxic?

Essential Elements: Must meet two criteria:

A) Direct: be part of a compound or reaction that the plant cannot survive without.

B) Indirect: i) In its absence, the plant does not complete its life cycle; ii) the element cannot be replaced, iii) the element must have an effect on the life of the plant and not only play the role of neutralizing unfavorable effects on the plant.

Beneficial Elements: They are not essential, plants can live without them, however, the presence of these elements can somehow contribute to the growth and production of plants.

Toxics Elements: Essential or not, the element is considered toxic when in high concentrations, it causes damage to plants.

Recent studies show that foliar application of Se in corn plants subjected to water stress increased water use efficiency, chlorophyll and carotenoid contents (Nawaz et al., 2016). In addition to these results, responses in antioxidant metabolism, growth and productivity gains were observed when Se was applied during the flowering in wheat (Souza et al., 2014), coffee (Matheus et al., 2021) and bean (Figueiredo) plants. et al., 2017). Furthermore, tomato fruits that received applications of Se sources had their biological age reduced and the storage time of the fruits was increased (Pezzarossa et al., 2014; Hernandez-Hernandez et al., 2019).

Zinc: dynamics in the soil-plant system and antioxidant metabolism

Zinc (Zn) is the 23rd most abundant element in the earth's crust and is present in the form Zn^{+2} and is adsorbed on the surface of soil particles with clays, organic matter and iron oxides (Malavolta, 2006). In soils, their average contents are concentrated in the ranges between 60 and 89 mg kg^{-1} (Broadley et al., 2007; Kabata-Pendias, 2011). However, in the soil solution, which represents the levels that will be available to plants, the levels are low and are influenced by management, pH, soil texture, organic matter content, microbial activity and concentrations of phosphorus and other cationic elements (Alloway, 2008; 2009; Broadley et al., 2007).

Although there have been improvements in soil management, it is estimated that 50% of soils cultivated with grains that are deficient in Zn (Alloway, 2008). Results about Brazilian soils are still few, however, Souza et al. (2014A) analyzed 41,390 georeferenced soil samples covering about 55 million hectares and found that the Zn contents in these soils were between 0.1 and 92.1 $mg.dm^{-3}$ and that the average was 4.67 $mg.dm^{-3}$. Also according to the authors, 58% of the area is at risk of Zn deficiency for plants due to high levels of P, pH and clay. Corroborating these results, Bispo et al. (2015) found that approximately 63% of the Brazilian savannah areas are at risk of Zn deficiency (Figure 4).

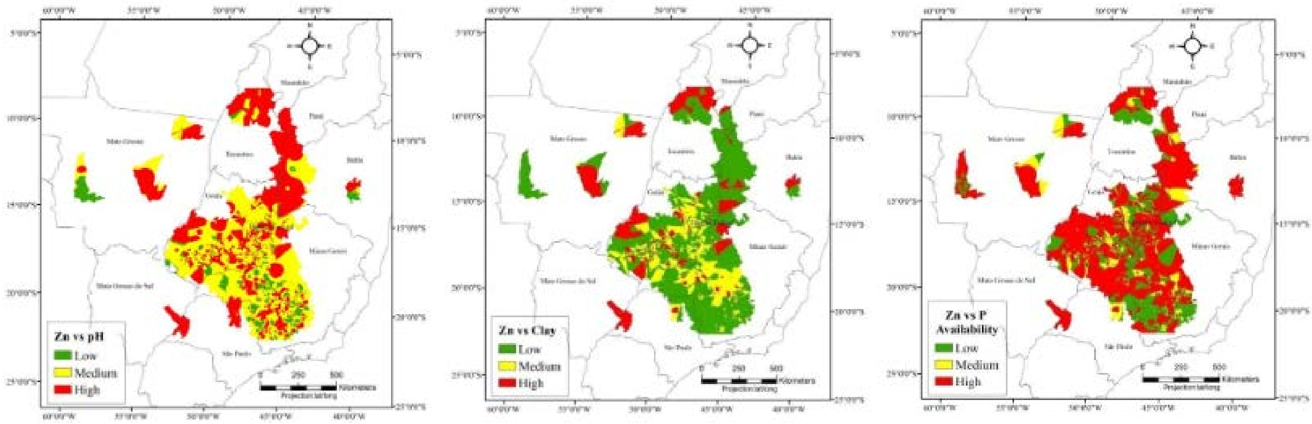


Figure 4. Geographical distribution of data for the interaction Zn and pH; Zn and Clay content and; Zn and P available in Brazilian savannah soils (n= 37,904 samples). Adapted from Bispo et al. (2015).

Plants absorb Zn in the form of Zn^{+2} and the concentration of this element in plants varies according to the species and environment in which it develops, however, for most, it varies from 20 to 120 mg kg^{-1} of dry matter (Malavolta, 2006; Alloway, 2008; Kabata-Pendias, 2011). The literature reports that Zn deficiency symptoms are characterized by shortening internodes and reducing the size of young leaves, which become chlorotic and lanceolate. The effect of Zn deficiency, both in soils and in plants, occurs all over the world and studies show that plants that received Zn respond in productivity or final quality (Malavolta; Vitti; Oliveira, 1997; Graham et al., 2001; Malavolta, 2006; Cakmak, 2008). Furthermore, responses to this fertilization vary according to species and genotype (Alloway, 2008; Cakmak, 2008; Cakmak et al., 2010; Souza et al., 2013; Souza et al., 2014B).

Zn is essential for carrying out several metabolic processes in the plant, among which are photosynthesis, protein synthesis, maintenance of membrane integrity and auxin metabolism and reproduction (Broadley et al., 2007; Palmgren et al., 2008; Hansch & Mendel, 2009). In addition, it acts to eliminate free radicals by composing enzymes such as NADPH oxidase, participating in Cu-Zn-SOD, CAT and POD (Cakmak, 2000; Hansch & Mendel, 2009; Mayer et al., 2008; Gupta et al., 2018). Therefore, maintaining adequate Zn levels is essential for the process of stress tolerance and/or recovery.

As it is directly linked to antioxidant metabolism, responses to Zn applications are observed in plant recovery metabolism, regardless of the cause of stress, whether biotic or abiotic, in the most diverse crops (Weisany et al., 2012; Li et al., 2012; Li et al., 2012; Li et al. al., 2013; Ma et al., 2017; Roosta et al., 2017; Laxa et al., 2019; Sofy et al., 2020; Tavanti et al., 2021).

Magnesium: dynamics in the soil-plant system and antioxidant metabolism

Magnesium (Mg) is one of the most recurring elements on the Earth's surface, occupying the eighth position with about 2% of the Earth's crust. Ferro-magnesian minerals from Igneous rocks are the main sources of Mg, followed by carbonates that have undergone some type of modification of these primary minerals (Metson 1974; Mikkelsen, 2010). In soil, Mg may be associated with clay minerals or in cation exchange sites. However, the amount of this element in these sites that goes to the soil solution is insufficient to maintain crop productivity. On the other hand, the Mg adsorbed in clays are responsible for supplying this element in the soil solution, as they are easily exchangeable and respect stoichiometric reactions (Metson 1974; Mikkelsen, 2010).

Plants absorb Mg from the soil solution in the form of Mg^{+2}, however, attention must be paid to the concentrations of ions such as K^{+}, Ca^{+2}, and NH_4^{+} in the soil solution, as these can reduce the availability of Mg to plants. Liming is the main source of Mg for crops, however, applications have not been sufficient to meet the demands of this nutrient (Altarugio et al., 2017). It is worth mentioning that as the reaction of limestone in the soil advances, there is an increase in the pH of the soil and a reduction in the availability of Mg, due to the decrease in the reaction of $MgCO_3$, from the moment that this soil pH reaches the value of 6.1 (Novais et al., 2007).

Every year the interest of researchers in working with this element has grown, due to its role in plant biochemistry and physiology (Cakmak & Yazici, 2010; Gransee & Furhrs, 2013; Taiz et al., 2017). In addition to being the central atom of chlorophyll, Mg is directly linked to processes such as photosynthesis, photorespiration, ackar transport and is a component of chlorophyll (Hawkesford et al., 2012; Taiz et al., 2017; Tranker et al., 2018; Rodrigues et al., 2021). Also, Mg participates in the activation of several enzymes such as glutathione synthase, Rubisco, phosphoenolpyruvate carboxylase, phosphatases and ATPases that have a direct role in plant metabolism and growth (Taiz et al., 2017; Rodrigues et al., 2021).

As mentioned above, the main sites of ERO production are chloroplasts, peroxisomes and mitochondria, organelles that are directly linked to photosynthesis or plant respiration. This happens because these organelles are responsible for receiving light radiation and converting it to the formation of carbohydrates, however, if this conversion does not occur, electrons accumulate in the cells and, consequently, the formation of EROs (Figure 1) (Santaniello et al., 2017; Pereira et al., 2020).

As an example of this accumulation of sugars leading to cell degradation was observed by Cakmak et al. (1994) in bean plants showing that plants deficient in K and Mg had, respectively, sucrose concentrations 6.3; 9.0 times higher in leaves when compared to the control treatment (Figure 5). According to the authors, this shows the strong relationship between Mg and K in the loading of sugar in the phloem.

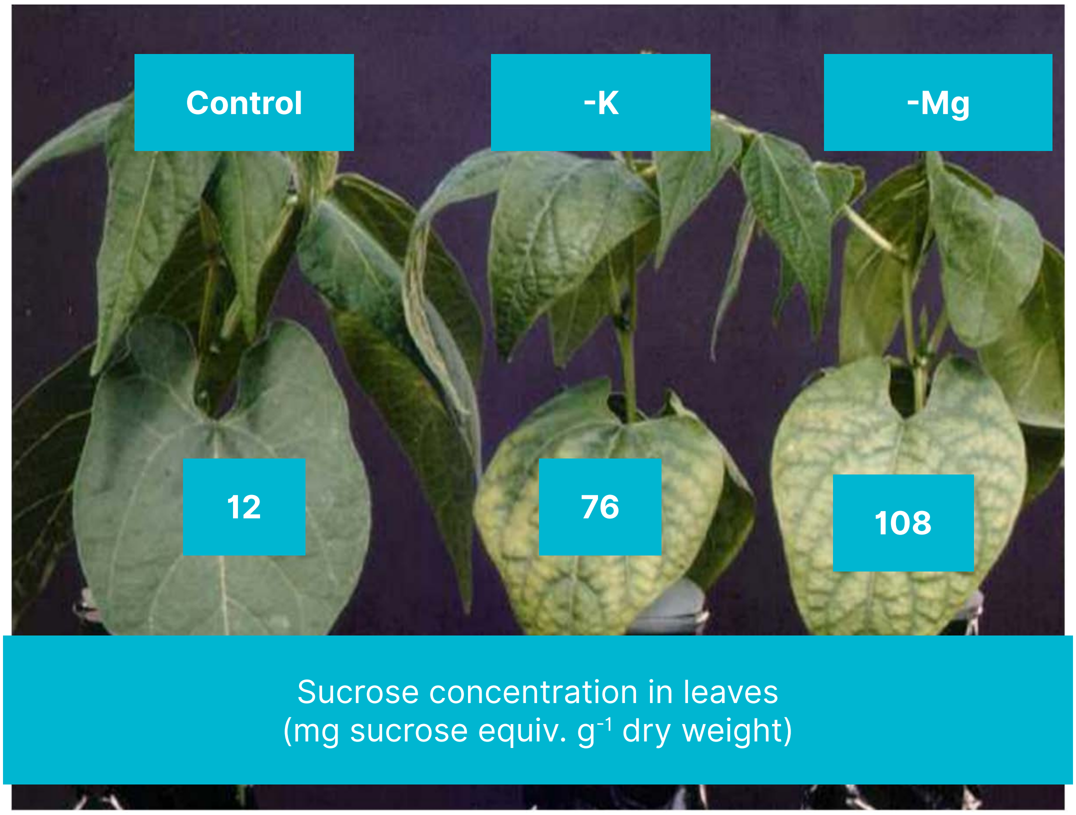


Figure 5. Sucrose concentrations in bean leaves with potassium (K) and magnesium (Mg) deficiency. Adapted from Cakmak et al. (1994).

Mg actively participates in this mechanism because, in addition to being the central molecule of chlorophyll, it increases Rubisco activity, increasing CO_2 fixation and assisting in the thermal dissipation of this energy so that cell damage does not occur. Thus, applications of Mg through the leaf not only contribute to the photosynthetic mechanism, but also increase antioxidant activity and carbohydrate translocation in the plant phloem, decreasing the generation of EROs and oxidative damage to chloroplasts (Cakmak & Kirkby, 2008; Gransee, 2008; Gransee & Furhrs, 2013; Gupta et al., 2018; Lanza, 2021; Rodrigues et al., 2021).

Recent studies have shown that plants under stress subjected to foliar application of Mg increased growth parameters, chlorophyll synthesis, carbon assimilation, water use efficiency and, consequently, improvements in productivity in the most diverse crops (Ahmad et al. al., 2018; Boaretto et al., 2020; Kibria et al., 2020; Rodrigues et al., 2021). In all these works there is a consensus that the application of Mg increases the activity of the antioxidant system and reduces oxidative damage and cell death.

Another time when plants are susceptible to stress is near the time of flowering or the beginning of pod/fruit development (Mattos-Jr et al., 2018). In this period, in addition to changes in the hormonal balance of plants, high concentrations of nutrients are required, both for nutrition and for tuber grains and fruits filling. Thus, foliar Mg supplements close to reproductive stages result in increases in productivity and improvement in the quality of the harvested product, especially if accompanied by small doses of N (Romheld & Kirkby, 2007).

Agronomic biofortification of plants: improving the quality of products that arrive on the table of Brazilians

Since plant nutrition is not so distant when compared to human nutrition, a new stage begins in Brazilian Agriculture and doors are opened for a more sustainable production aimed at food security. For this, disruptive and innovative products are necessary so that we can deliver high quality food to the population. With that in mind, biofortification is a cheap, sustainable alternative that will improve people's lives.

Did you know...

...that biofortification processes can be:

Agronomic: Enrichment through management (fertilization, for example).

Genetic - Conventional:

Carried out through conventional genetic improvement (breeding the plants with the best performance for certain characteristics).

Genetic - Transgenic:

Carried out by inserting genes of specific interest (e.g. Golden Rice).

Industrial:

We still have industrial fortification, which is the increase of nutrients in products for industrialization, such as table salt and wheat flour.

Biofortification is the process by which an increase in the nutrient content is sought in agricultural products to be harvested in order to enrich the final product with a certain element (Welch, 2005; White & Broadley, 2005; Gómez-Galera et al., 2010;). Biofortified crops contain better agronomic and nutritional characteristics than those that have not undergone this process (Welch & Graham, 1999).

The low diversification in the composition of the diets along with the restricted access of the population to foods with high levels of nutrients has brought situations of nutrient deficiency to the population. It is estimated that over three billion people worldwide suffer from food security and have deficiencies in Fe, Zn, I, Se and vitamin A (Graham et al., 2001). Also, elements such as Ca, Mg and Cu may be deficient in the diets of some populations, but without any studies (Welch & Graham, 2004; White & Broadley, 2005). Therefore, biofortification is a sustainable way to improve human nutrition, especially for the poorer families.

In Brazil, there are no reliable results on this subject, in addition, the economic and social differences between the people who live here make it difficult to carry out a more detailed study that correlates to the entire population. Thus, Fe deficiency is assumed to be the most widespread, especially among children and pregnant women, in addition to Zn and Se deficiencies must be similar to the international standard, i.e., there are deficiencies (Moraes, 2008).

However, in order to increase nutrient levels in plants, it is necessary to take into account the metabolic, molecular and physiological processes on which Plant Mineral Nutrition is based (Cakmak, 2008; Taiz et al., 2017).

Nutriduo

Based on all the evidence presented and **Innovating for a Sustainable Future**, with higher quality products delivered to the population, **ICL** presents **Nutriduo** and inaugurates a new era in Brazilian Agriculture.

Innovations begin not only because it is a completely new product, but also because it offers concepts that involve plant nutrition, human nutrition and food security.

In order to reach levels of excellence, **Nutriduo** actively acts on plants and there are three lines of defense for this:

a) Photoprotector – The presence of Se increases the production of carotenoids, improving the energy dissipation of the photosynthetic apparatus before it can cause damage to the plants;

b) Activation of the plant's antioxidant system – The application of micronutrients and Se, in low concentrations, has a direct effect on enzymes that fight the oxidative stress of plants such as SOD, CAT, POD and APX;

c) Transport of photoassimilates from the leaves to the drains - elements such as Mg, K and Se improve the flow of photoassimilates in the phloem vessels, increasing the partition of carbohydrates from the leaves (source) to the parts to be harvested - roots, tubers, pods, fruits (drains).

In order to perform these functions, **Nutriduo** has an innovative source of Mg in its composition, more efficient when compared to the sources of this nutrient used in national agriculture until now. This new source, which was developed by the **Research and Development of ICL**, consists of a Mg chelate with high stability comprising pH ranges between 1.5 and 13, i.e., superior to all other sources of Mg chelates present on the market (Figure 6).

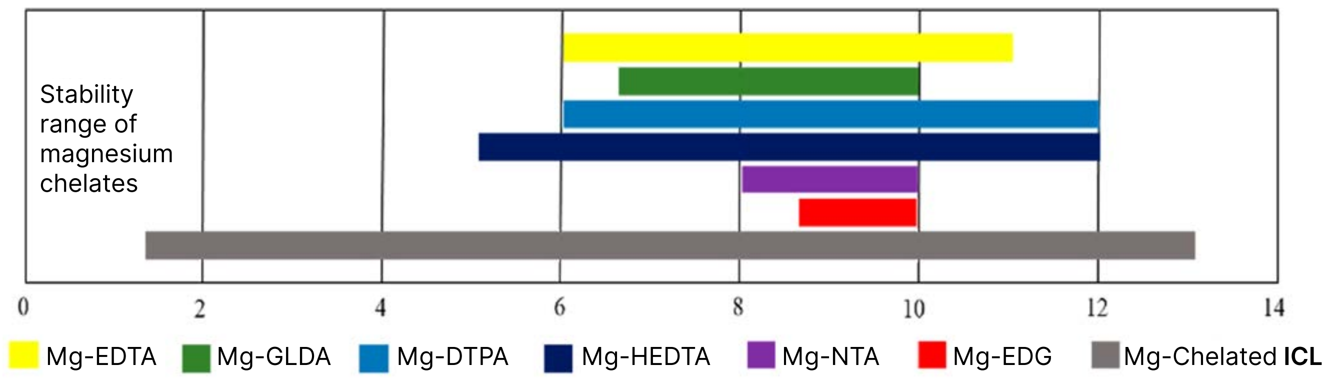


Figure 6. Stability range of different magnesium chelates as a function of pH (Adapted: **Research and Development Department of ICL**).

In addition to being a modern source of Mg, **Nutriduo** has very high solubility (1000g/L water), providing a greater solubilization speed and faster preparation of application solutions and high compatibility with pesticides and amino acids. In other words, with these technical benefits, there are no problems with clogged nozzles or filter and there will be no residue leftovers at the bottom of the sprayer tank.

Nutriduo contains a balance of nutrients suitable for the most diverse crops to deliver the best results when applied. Additionally, **Nutriduo** contains Selenium (Se) in its composition, an element that is considered beneficial to plants but essential for animals and humans. Therefore, with the application of this element, we will be working on the stress-relieving metabolism in plants, enriching them with Se, Mg and Zn and, when looking at the end of the chain, benefiting lives!!!

ICL is a cutting-edge company, which innovates in nutrient sources (Mg chelate with patent pending); Selenium complex to improve plant metabolism; Balanced nutrients that provide better results and, finally, we are concerned with the food security conditions of the population.

Nutriduo: Results in the field!

Over the last few years, dozens of tests have been carried out in the field out to evaluate the performance and define the positioning of the product. For soy, the best application time is at the R3 stage and at a rate of 1.0 kg ha^{-1}. As a result, in the most diverse regions of the country, it was found that after the application of **Nutriduo** there was an increase in the levels of Se in the grains (Figure 7) and an increase in productivity (Table 1).

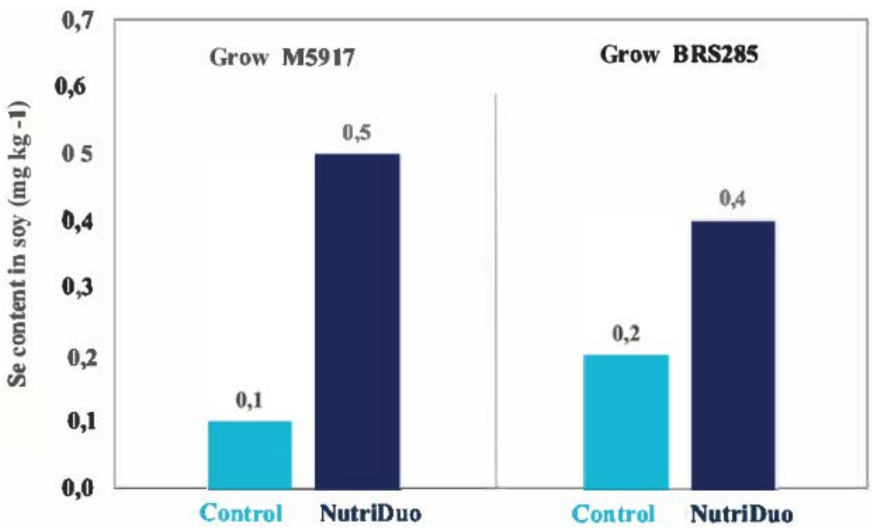


Figure 7. Selenium content in soy cultivars in response to NutriDuo application. Mean data from management with NutriDuo. Capão Bonito/SP. Adapted from Guilherme et al., 2020.

Another point worth mentioning is that by applying **Nutriduo**, the soy plants were able to keep their proline levels low, showing that these plants were not under stress (Figure 8A). Proline protects proteins from denaturation, fights free radicals and stabilizes cell membranes through interactions with phospholipids. In other words, plants under stress have high levels of proline so that cell oxidation does not occur, nor does turgor loss occur, thus maintaining the essential activities of the biochemical metabolism of plants (Claussen, 2005; Farooq et al., 2005).

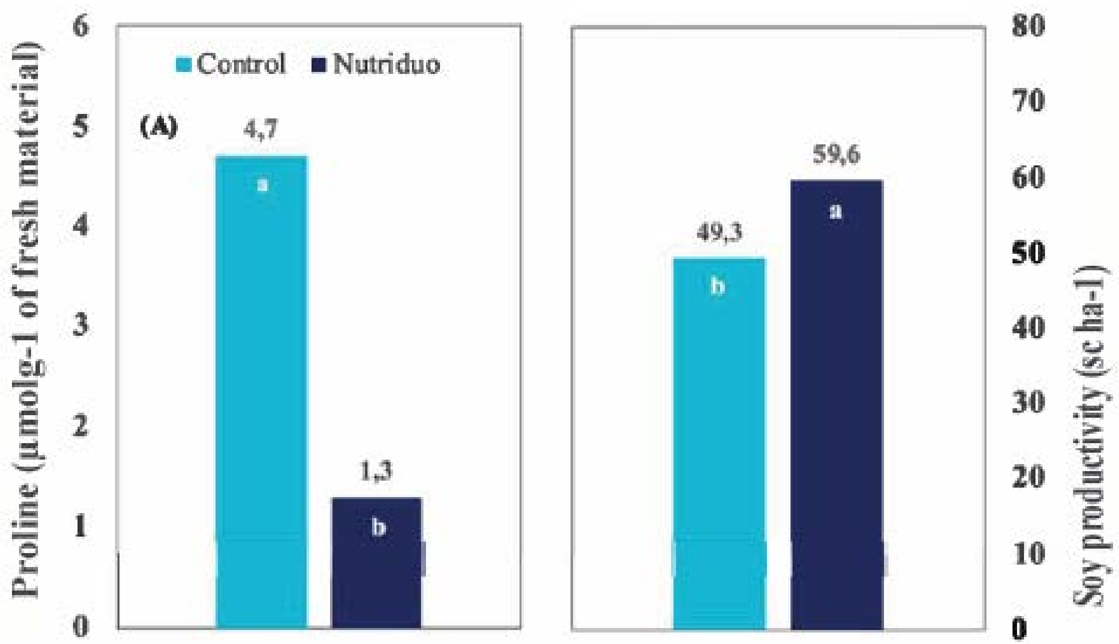


Figure 8. Proline levels (A) and grain yield (B) of soy in response to NutriDuo application. Means followed by the same letter do not differ from each other by Tukey's test at 5% significance. Patos de Minas/SP. Adapted from Fagan (2020).

Proline synthesis consumes a large amount of N from the leaves (between 0.4 and 0.6%) thus high proline synthesis can consume nitrogen that could be used in other plant processes ranging from growth to productivity (Ernst et al., 2000). This fact can be verified in Figure 8B, where the plants that received the **Nutriduo** application had lower proline production, indicating that the plants had a lower stress index and responded with higher productivity.

Continuing the work, but now in commercial soy areas across the country, 10 demonstrative fields were tested whose consistency of results is shown below (Table 1).

City	Standart (sc/ha)	Nutriduo (sc/ha)	Difference (sc/ha)
Maracaju - MS	66.23	69.3	3.07
Tibagi - PR	63.33	64.33	1.00
Moreira Sales - PR	53.3	54.13	0.83
Cruz Alta - RS	62.47	64.50	2.03
Campo Novo do Parecis - MT	49.28	55.46	6.18
Castro - PR	77.43	78.86	1.43
Santa Bárbara - RS	97.40	100.32	2.92
Erechim - RS	74.00	78.00	4.00
Catuípe - RS	68.90	71.26	2.36
Capão Bonito - SP	90.50	92.30	1.80
Iracemápolis - SP	104.80	106.30	1.50

Source: **ICL´s Market Development Department**

Nutriduo: Nourishing plants and benefiting lives!!

1,0 kg/ha in R3
(start of pod formation)

Innovation Center

The Innovation Center was opened in 2013, in Iracemápolis - SP, with the aim of accelerating the development of innovative products and contributing to the increase in productivity and food supply. Annually, there are over 3,000 plots, with experimental protocols in plant physiology and nutrition, resulting in an investment of over 18 million reais to provide farmers with a state-of-the-art portfolio and solutions to meet the main needs of crops in different agricultural regions.

And, for all this to happen in a structured manner, we have over 50 highly specialized professional researches, with excellent academic training, who have graduated from several universities recognized worldwide and have master's and doctoral degrees.

In 2020, the **Innovation Center** was accredited by the Ministry of Agriculture, Livestock and Supply (MAPA) and now, the results generated here can be used to register new fertilizers, perform bioassays to register biofertilizers and fertilizers to be applied through seeds.

According to MAPA's list of private research institutions, we are the only company that works exclusively in the area of plant physiology and nutrition that has a research center registered by MAPA for research on fertilizers.

This certification confirms our values and commitment to help feed the world in an ethical and sustainable manner.

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