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Review of Research on Nutritional Physiological Mechanism and Nutritional Diagnosis of Magnesium in Fruit Trees

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Abstract Magnesium is an essential nutrient element for the growth and development of fruit trees. It not only participates in photosynthesis of plants, but also promotes physiological and biochemical reactions such as carbohydrate and protein synthesis, enzyme activation, and reactive oxygen species (ROS) metabolism. Magnesium deficiency in fruit trees will directly influence the growth and development of trees and the improvement of fruit quality. This study mainly reviews the nutritional and physiological mechanism of magnesium in plants and the nutritional diagnosis of magnesium deficiency in fruit trees, in order to provide a theoretical basis for further research on magnesium nutrition in fruit trees, and accordingly provide a certain reference for the application of magnesium fertilizer.

Key words Magnesium element, Fruit tree, Physiological mechanism, Nutritional diagnosis

1 Introduction

In 1839, Sprengel *et al.* [1] identified magnesium as an essential nutrient element for plants. Magnesium participates in various physiological and biochemical processes in plants in many ways, and its role in plant growth, development and metabolism cannot be replaced by other nutrients[2–3]. Magnesium is an important component of chlorophyll, can promote the formation of chlorophyll, participate in photosynthesis and carbohydrate metabolism, is a catalyst for various enzymatic reactions such as RNase and ATPase, and participates in processes such as reactive oxygen species (ROS) metabolism[2,4–5].

Foreign scholars started early in the research about the physiological mechanism of magnesium nutrition. For example, extensive studies have been carried out on the absorption and chemical reaction mechanism of magnesium[6–8]. In recent years, the phenomenon of magnesium deficiency in fruit trees has become more common and increasingly serious in the whole country of China. Then, domestic scholars start to focus on this research. The studies of Peng Liangzhi *et al.* [9] and Zhang Guangyue *et al.* [10] showed that magnesium deficiency is common in Newhall navel oranges in southern Jiangxi and southern Hunan provinces. Findings of Wu Guangliang *et al.* [11] showed that magnesium can affect the growth effect of *Ginkgo biloba*; Tang Xiaofu *et al.* [12] showed that magnesium affects the growth and development of *Cucumis melo* var. makuwa. It can be seen that it is of great significance to explore the physiological mechanism of plant magnesium nutrition and nutritional diagnosis for fruit tree production.

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2 Physiological functions of magnesium nutrition in plants

2.1 Activation mechanism of magnesium on enzymes Most enzymatic reactions require magnesium for activation. The mechanism of enzyme activation: after Mg^{2+} cooperates with the enzyme, the conformation of the enzyme changes, and the bound nucleotides inside the enzyme are more exposed and accessible to the substrate, which increases the affinity between the enzyme and the substrate, thereby increasing the number of enzymes in the activated state.

Magnesium can activate various phosphomutases and phosphokinases in plants. For example, the substrate for most ATPases is Mg-ATP. Magnesium ions build a bridge between the pyrophosphate structure of ADP or ATP and the enzyme molecule, and the formed complex can activate the ATPase[13]. Besides, magnesium can also promote plant carbon assimilation efficiency by regulating RuBP carboxylase, and the combination of Mg^{2+} with RuBP carboxylase increases its Km and Vmax for CO_2[14]. Under light, H^+ enters the thylakoid from the matrix and Mg^{2+} enters the matrix, providing the optimal conditions for RuBP carboxylase (*i.e.* pH > 6 and higher Mg^{2+} concentration)[15]; in the dark, the activation of Mg^{2+} and RuBP carboxylase is opposite.

2.2 Mechanism of magnesium effect on plant photosynthesis Magnesium plays a crucial role in maintaining the structure of the chloroplast and is present in the center of the porphyrin ring of the chlorophyll molecule. Magnesium can account for 2.7% of the molecular weight of chlorophyll and participate in the composition of chlorophyll[16]. Mg^{2+} can induce stacking of photosynthetic membranes. Mg^{2+} can induce the stacking of thylakoid membranes to form grana at low concentrations, which is favorable for capturing light energy and facilitating energy transfer between photosynthetic membrane pigments[17]. Mg^{2+} can also reverse the damage of unsaturated fatty acid-linolenic acid to photosynthetic membranes. Mg^{2+} affects photosystem II (PS II) activity and primary light energy conversion efficiency, The mechanism is that Mg^{2+} can increase the chlorophyll variable fluorescence Fv and Fv/Fm (the ratio of variable fluorescence to maximum fluorescence)[18], thereby prompting plants to convert more light energy into chemical energy. Mg^{2+} can adjust the distribution of excitation energy between the two photosystems and improve the ratio of PS II to PS I relative fluorescence yield. The findings of Li Yan *et al.*[19] showed that in the state of magnesium deficiency in longan, the distribution and regulation ability of excitation energy between the two photosystems was reduced. In addition, Mg^{2+} influences the combined electron transfer rate. Under saturated light intensity, Mg^{2+} can significantly increase the electron transfer rate of PS II in shade and sun plants (heliophyte). The enhancement of the electron transfer rate of PS II by Mg^{2+} is related to their activation of the PS II reaction center. Studies have shown that magnesium deficiency reduces the photosynthetic rate of cucumber leaves[20], and low magnesium stress significantly reduces the net photosynthetic rate of leaves of *Vernicia fordii* (Hemsl.) Airy Shaw[21].

2.3 Effects of magnesium on protein synthesis and nitrogen metabolism in plants As a bridging element linking ribosome subunits, Mg^{2+} can ensure the stability of ribosome structure. Under the circumstance of low magnesium, 80S ribosomes are broken down into 40S and 60S ribosomes. When the concentration of Mg^{2+} increases, 40S and 60S ribosomes will be recombined and aggregated into 80S ribosomes. When the concentration of $Mg^{2+} > 0.001$ mol/L, it will cause the polymerization of 80S ribosomes to form 120S ribosomes[22]. Besides, Mg^{2+} is also involved in transcription process, such as DNA and RNA synthesis, translation process, amino acid synthesis process. Nitrate reductase is the rate-limiting enzyme in nitrogen metabolism. Mg^{2+} influences the nitrogen metabolism process by regulating the activity of a series of enzymes in nitrogen metabolism such as nitrate reductase; it can also promote nitrogen absorption and assimilation by activating glutamine synthase[23]. In addition, some studies have shown that magnesium deficiency can hinder the accumulation of photosynthetic products, thereby hindering the growth of fruit tree branches and fruits[13].

2.4 Effects of magnesium on the metabolism of reactive oxygen species in plants The strong oxidizing ability of reactive oxygen species can lead to lipid peroxidation of biological membranes, destruction of membrane systems, and changes in membrane permeability, which in turn affects tree growth and fruit development[24]. The plant keeps the lowest level of reactive oxygen species by inhibiting the generation of reactive oxygen species (ROS). In addition, there are also reactive oxygen species scavenging systems, including enzymatic and non-enzymatic systems. The enzyme system includes superoxide dismutase (SOD), peroxidase (POD), and catalase (CAT); non-enzymatic systems include ascorbic acid (AsA), vitamin E, glutathione (GSH), *etc.*[16]. Chloroplast is an important part of reactive oxygen species production in plants. The study of Guo Pengcheng *et al.*[15] showed that the increase of reactive oxygen species caused by magnesium deficiency is the main reason for leaf yellowing. Another study showed that under magnesium deficiency stress, the chlorophyll content of the leaves of *Citrus tachibana* was significantly reduced, while the activities of CAT and POD were significantly increased, while the activities of SOD and APX did not change significantly, indicating that magnesium deficiency can lead to the accumulation of reactive oxygen species in leaves, and the high activity of POD and CAT may be related to the scavenging of reactive oxygen species[25].

3 Nutritional diagnosis of magnesium element

The magnesium content of plant leaves needs to be above 0.20% (dry basis), if it is less than 0.20%, there is a possibility of magnesium deficiency. Different plant species, varieties, organs and developmental stages have different critical concentrations of magnesium. Generally speaking, when the magnesium content of leaves is greater than 0.4%, it indicates that the supply of magnesium is sufficient[26]. From the appearance, the prominent manifestations of plant magnesium deficiency are the decrease in the chlorophyll content, the chlorophyll yellowing of leaves, the strong mobility of magnesium in the phloem, and the symptoms of magnesium deficiency first appear on old leaves[27]. The study of Liu Shuyi *et al.*[27] showed that magnesium deficiency in grapes can lead to leaf shrinkage and shedding and bare branches. In addition, magnesium-deficient plants will also have twigs, few roots, delayed flowering, and pale flowers[28]. In terms of cell structure, some researchers have found that magnesium deficiency can lead to thinning of leaf thickness and cross-section, loss of cell content and irregular arrangement of cell organization, and decrease in the number of grana and chloroplasts[29-31]. In addition to the diagnosis of magnesium nutrition by appearance and cellular structure, proteomics was also used to investigate. For example, Peng Haoyang *et al.*[32] studied the effects of magnesium on snow mandarin and found that 89 proteins in leaves of *Citrus sinensis* (Linn.) Osbeck and 32 proteins in root leaves were changed under magnesium deficiency conditions. In recent years, domestic scholars have carried out in-depth research from genes, for example, using cDNA-AFLP technology to screen genes related to magnesium deficiency stress in *Citrus reticulata*. Through analysis, it is found that magnesium deficiency can influence photosynthesis, redox reaction, protein and carbohydrate metabolism, cell tissue synthesis, stress response, transcription and translation of leaves of *C. reticulata*[33].

4 Research prospects

Magnesium is an essential mineral element for the growth and development of fruit trees. In recent years, the research on the nutritional physiology of magnesium has receiving more and more attention. Many scholars have studied the effects of magnesium fertilizer application on plant growth and development, the difference in the effects of different magnesium fertilizer applications, and the interaction of magnesium with calcium and potassium elements. However, the above studies mainly focus on plants and crops. There are few and in-depth studies on the effects of magnesium on fruit trees. In order to effectively manage the application of magnesium fertilizer in fruit tree production, it is of great significance to study the mechanism of magnesium absorption by fruit tree plants, the effects of magnesium on fruit tree stress resistance, as well as the interaction between magnesium and other mineral elements.

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