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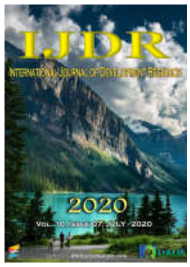

**RESEARCH ARTICLE** **OPEN ACCESS**

# PHYSIOLOGICAL PLANT RESPONSES TO PHOSPHORUS DEFICIENCY: A LITERATURE REVIEW

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**ABSTRACT**

Phosphorus (P) is a macronutrient that performs functions in several physiological processes, becoming essential for the proper growth and development of plants. P limiting conditions, causes several damages, since it affects the cell homeostasis, promoting reductions in the photosynthetic rate, in respiration, and consequently can cause reductions in the production of cultures. This review shows the advances in the understanding of the physiological mechanisms of plants to increase the efficiency in the absorption of P under limiting conditions. The study was based on a bibliographic review, through the analysis of databases in scientific articles in public and private, national and international institutions. The searches were carried out on scientific bases such as: Pubmed, NCBI, SciELO and Google Scholar. The results show that under P limiting conditions, plants have different physiological mechanisms to increase the efficiency in the absorption and use of P. Among the observed mechanisms have changes anatomical root morpho, exudation of organic acids, use of high affinity transporters, as well as association with mycorrhizae. The knowledge of such advances allows genetic improvement programs, to target more efficient genotypes in the absorption and use of P under limiting conditions.



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## INTRODUCTION

The plants are often exposed to various environmental stress, including drought, soil acidity, extreme temperatures, mineral nutrient deficiency or toxicity (Mohammad *et al.,* 2017), which affect their proper growth and development, consequently reflecting on the productivity of agricultural crops. Around 60% of arable land in the world has deficiencies or toxicity problems of mineral nutrients. In this context, the availability is compromised by various factors, such as the pH of the soil, the presence of cation, microbial activity (Fageria *et al.,* 2008), associated with improper handling in the planting areas. Thus, increasing the efficiency of nutrient use, considering all macronutrients (N,P,K,Ca,Mg,S) and micro nutrients (Cl, Fe, B, Mn, Zn, Cu, Mo and Ni) is a challenge for agriculture (René *et al.,* 2017; Dimkpa e Bindraban, 2016; Bindraban *et al.,* 2015; Uchida, 2000). Phosphorus (P) represents about 0.2% of the dry weight of plants. Through various chemical reactions P is incorporated into organic compounds in plants, which include nucleic acids (DNA and RNA), phosphoproteins, phospholipids, sugar phosphates, enzymes and compounds rich in energy, such asadenosine triphosphate (ATP). In addition, P modulates several cellular functions in signal transduction pathways (Czarnecki *et al.,* 2013). However, the main source of P for plants is inorganic phosphate (Pi), characterized by its low availability and mobility (Schachtman *et al.,* 1998). Approximately 80% (on average) of phosphate fertilizers applied cannot be explored by plants (Bayle *et al.,* 2011), due to adsorption to Fe oxides/hydroxides, Al hydroxides, as well as Ca carbonate surfaces; resulting in the formation of Fe-phosphates, Al-phosphates and Ca-phosphates, respectively (Balemi e Negisho, 2012). Interestingly, plant species or even genotypes of the same species exhibit plasticity in the development of responses to changes the environmental conditions, which are complex and involve numerous physiological, molecular and cellular adaptations (Lopez-Bucio *et al.,* 2003). In this context, the term efficiency refers to the ability of plant species to absorb and use nutrients or even to relate the productivity of crops according to the unit of the nutrient applied to the soil in the form of fertilizer (Fageria e Baligar, 2005). Efficiency mechanisms for the use of P in plants include absorption efficiency (the ability of a plant to absorb more P under limiting conditions), utilization efficiency (the ability of a plant to produce a higher yield of dry matter per unit Absorbed P) (Balemi e Negisho, 2012), and the translocation efficiency (the P partition in the roots and in the aerial part) (Wang *et al.,* 2010). In view of the aspects mentioned above, this review aims to present the understanding of physiological mechanisms of plants to increase the efficiency of P absorption under limiting conditions.

## METODOLOGY

This study is carried out by bibliographic review, in the period from 1981 to 2019, developed through scientific articles in public and private national and international institutions. The research were carried out on scientific bases such as: Pubmed, NCBI, SciELO and Google Scholar. The articles were selected using the following descriptors: "phosphorus deficiency", "adaptation mechanisms"; “Morphoradicular responses”.

# RESULTS AND DISCUSSION

The three-dimensional configuration of the root system of the plants is of great importance to improve the efficiency of acquisition and use of nutrients in the soil, and thus enhancing the crop yields (Li *et al.,* 2015). The evolutionary consequences of the decline in the availability of phosphorus (P) in soils, resulted over time in an extremely diverse set of plant species with root adaptations (reduction in primary root growth, development of lateral roots, formation of root hair) aiming to acquire P and use it internally in an efficient manner (Vejchasarn *et al.,* 2016; Muller *et al.,* 2015; Cancellier *et al.,* 2012; Abel, 2011; Lambers *et al.,* 2006). Research suggests that P would be perceived locally and act as a signal for the control of the root system and lateral root formation (Niu et al., 2012; Péret *et al.,* 2011; Sousa *et al.,* 2010). Grossman e Rice (2012) found in barley plants that the proportion of root weight is higher at low levels of phosphorus fertilization. According to Gruber *et al.* (2013) a P deficiency (50 μ M P) promotes a decrease in primary root length in plants of Arabidopsis thaliana, which was accompanied by an increase in the density of lateral roots of the first order.Lopez-Bucio et al. (2003), studying plants of Arabidopsis thaliana cultivated under P deficiency conditions, found increases in gene expression for P carriers in membranes, associated with high concentrations of auxin in their meristems.

Several mechanisms are necessary to activate the root architecture in response to the P change, which depend on changes in various growth regulating factors, such as levels of auxins, ethylene, cytokinins, nitric oxide, abscisic acid, as well as a performance of several genes, consequently allowing plants to adapt to P deficiency conditions (Niu *et al.,* 2013). Plants have developed other mechanisms for better efficiency in the absorption of P, for example, we have the exudation of low molecular weight organic acids, the release of protons, the activation of enzymes such as phosphatases and phytases, the association of mycorrhizae, as well as activation of high affinity P carriers (Balemi e Negisho, 2012). Egle *et al.* (2003) studying Lupinus cultivars found increases in the rate of citrate exudation around 67% for L. albus, 37% for L. angustifolius and 72% for L. luteus in conditions of P deficiency. In rice plants, malic acid was the most prevalent organic acid present in the root exudates, when subjected to concentrations of 10.3 to 89.5 μmol plant -1 d -1 of P (Bhattacharyya *et al.,* 2013). Machado e Furlani (2004) studying the activity of the acid phosphatases enzyme in the growth of maize genotypes, verified that the genotypic variability must be known and considered before the use of the enzyme activity as an indicator of adaptation and efficiency of the use of P under conditions limiting. Studies by Ramesh *et al.* (2011) demonstrate that in soybean plants activities of phosphates varied according to availability of P in the soil.The plants are able to selectively select Pi (inorganic phosphorus), selective transport of compounds through cells is mediated by membrane transporters specific (Rausch e Bucher, 2002). Plants have specialized transportation at the root/soil interface for the extraction of Pi, from solutions with micromolar concentrations, as well as other mechanisms to transport Pi through the membranes between intracellular compartments (Balemi e Negisho, 2012; Nussaume *et al.,* 2011;). All dicotyledonous and monocotyledonous plant Pi carriers have been grouped into four sub-families, PHT1 to PHT4, which are located mainly in the plasma membrane, chloroplasts, mitochondria, and Golgi apparatus. For example, in rice, 13 genes were isolated in the Pht1 family and eight members were functionally characterized among them, OsPT1, OsPT6, OsPT9 and OsPT10, which are highly expressed in roots and responsible for the absorption of Pi (Ye *et al.,* 2015). Another mechanism used by plants to improve efficiency in the use of P is through the use of P-independent enzymes in the glycolytic pathways (Balemi e Negisho, 2012). However, it is important to destac that there is a threshold between the availability of P and the amount remaining in the soil, this nutrient can be lost and can pollute aquatic ecosystems, instigating ecological issues such as eutrophi-cation, consequently making it an expensive and ecologically unviable practice. Therefore, research on Pi nutrition in plants should take into account changes in agricultural practices that would be economically and environmentally beneficial (Kisko *et al.,* 2018), and that consider species characteristics or even genotypes within the same species that use and absorb P efficiently.

### Conclusions

This work has shown that phosphorus (P) is indispensable for proper growth and development of plants. In this way, adequate levels of P in the soil are necessary to maintain the cellular homeostasis of the plants, and consequently for them to demonstrate their full genetic potential. Within this perspective, the knowledge explained is important for genetic improvement programmes, obtain genotypes that are more efficient in absorbing and using the phosphorus available in the soil.

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