Scholars Academic Journal of Biosciences
Abbreviated Key Title: Sch Acad J Biosci
ISSN 2347-9515 (Print) | ISSN 2321-6883 (Online)
Journal homepage: https://saspublishers.com

OPEN ACCESS

Life Science

Research Progress on the Tolerance of Abscisic Acid in Plants to Abiotic Stresses

Li Luo[1], Xuefei Li[1], Jiayi Tan[1], Wenrui Liu[1], Fuquan Ye[1], Zhangyuan Hu[1], Jia Tian[1]*

[1]College of Life Science and Technology, Heilongjiang Bayi Agricultural University, Daqing 163319, China

DOI: https://doi.org/10.36347/sajb.2024.v12i07.007 | **Received:** 15.07.2024 | **Accepted:** 28.08.2024 | **Published:** 31.08.2024

***Corresponding author:** Jia Tian
College of Life Science and Technology, Heilongjiang Bayi Agricultural University, Daqing 163319, China

Abstract **Review Article**

The growth and development of plants are inhibited by abiotic stress, which is one of the factors limiting crop yield. Abscisic acid (ABA) is an important phytohormone and plays a key role in plant response to abiotic stresses. In this review, abscisic acid was introduced from its discovery, distribution and transportation. It was discussed the role of abscisic acid in abiotic stresses from three aspects, drought stress, salt stress and high temperature stress, and the application prospect of abscisic acid in agriculture was prospected.

Keywords: Abscisic acid, Abiotic stresses, Phytohormone, Stress Tolerance.

1. INTRODUCTION

Plants are the basic producer of ecosystem in nature, their growth and development are not only affected by biological factors, but also various abiotic stresses. Abiotic stresses refer to various pressures caused by abiotic environmental factors that adversely affect the growth and development of organisms. Salt stress, drought stress, cold stres, heat stress, enhanced ultraviolet radiation, nutritional deficiency and excess are all abiotic stresses. Abiotic stresses affect plant growth [1], change plant morphology [2] and decrease photosynthesis [3]. Abiotic stresses have significant potential to cause ~51%–82% crop yield loss in major food crops of global agriculture [4].

Abscisic acid (ABA) is one of the five major phytohormone hormones in plants [5], which is the key regulator of plant growth and development and mediator of environmental stress responses. It not only plays a role in physiological processes such as seed dormancy, plant growth inhibition and organ abscission [6], but also participates in the response of plants to various abiotic stresses, and it is recognized as a stress hormone [7]. This review described abscisic acid, summarized the role of abscisic acid in drought stress, salt stress and heat stress (high temperature stress), and prospected the application prospect of abscisic acid in cultivating stress tolerance plants and improving crop productivity and quality by agricultural biotechnology strategy.

2. Abscisic acid

2.1 Discovery of abscisic acid

In 1950s, people gradually paid attention to the effects of growth inhibitory substances on abscission and dormancy, and it was generally believed that phenolic compounds were the main growth regulators of plants. In 1963, Frederick Addicott and his associates found a substance from cotton fruits that could significantly promote the petiole shedding of cotton seedling explants, called abscisin II [8]. Wareing *et al.*, isolated dormin from sycamore maple leaves. In 1965, Wareing and others compared the chemical properties of dormin and abscisin II, and confirmed that they were the same substance, and named as abscisic acid [9].

2.2 Distribution of abscisic acid

Abscisic acid is widely distributed in all higher plants [10], and there are two forms in plants, namely free form and bound form. Its content is high in seeds, mature and dormant seeds, leaves, root tip areas and fruits. Abscisic acid can also be synthesized in flowers [11]. The content of abscisic acid is higher in the tissues and organs that are about to be shed or enter dormancy [12] and in plants under stress conditions [13]. For example, the ABA content in plants will increase under drought stress to enhance the stress resistance of plants [14].

2.3 Transportation of abscisic acid

Abscisic acid is mainly transported in free form [15] and can be transported for a long distance [16]. It can be transported through phloem and xylem for a long distance, from synthetic parts (such as leaves) to functional parts (such as roots). At the same time, ABA can be transported from hormone-synthesizing cells to nearby and distant cells [17], and also from vascular tissue to guard cells [18]. The translocation of ABA between cells, tissues and organs play important roles in whole plant physiological response to abiotic stress conditions [19].

3. Abscisic acid and abiotic stresses

3.1 Abscisic acid and drought stress

Drought is a recurring extreme weather event on land, which poses a serious threat to ecology and agricultural production [20]. Drought stress has a significant impact on the growth and development of plants. Under drought stress, plants appear short, withered leaves and branches, and so on. The water absorption of plants is also limited, and the swelling pressure of cells is reduced, which leads to the obstruction of cell elongation, and then the overall growth rate of plants is significantly slowed down. Abscisic acid is a metabolic antitranspirant [21].

Abscisic acid usually plays a key role in the response of plants to drought [22], and when plants suffer from drought stress, their ABA content will increase [14]. Abscisic acid can close stomata and reduce water loss by reducing transpiration rate [23]. At the same time, ABA can also enhance the water absorption capacity of roots, so that plants can better cope with drought environment [24]. ABA can promote the synthesis and accumulation of osmotic regulation substance, such as proline and soluble sugar, to adjust the osmotic potential in plant cells and improve the tolerance of plants to drought stress. Studies showed that after exogenous ABA treatment, the proline content in roots and leaves of maize increased significantly, the osmotic ability of leaves increased, and the water potential difference between roots and leaves increased, further enhancing the tolerance of maize to drought stress [25]. Abscisic acid can regulate plant stress resistance by regulating the expression of drought-resistant genes [26-30] and enhancing the activity of antioxidant enzymes in plant cells [31]. Related studies showed that the contents of H_2O_2 and malonaldehyde (MDA) in the early seedlings of *Onobrychis viciifolia* soaked by ABA were less than those in the early seedlings of *Onobrychis viciifolia* soaked without ABA. The activities of superoxide dismutase (SOD), peroxidase (POD) and catalase (CAT) in the early seedlings of *O. viciifolia* soaked by ABA increased at first and then decreased, while the activities without soaking decreased significantly. Those show that ABA can alleviate the oxidative damage of *O. viciifolia* under drought stress, and also improve the antioxidant enzyme activity of *O. viciifolia*, thus alleviating the oxidative damage caused by drought stress [32]. Under drought stress, ABA can also adapt to the environment by regulating the growth and development of plants. For example, by inhibiting the growth of stems, leaves and other above-ground parts to reduce water consumption, promote the growth and development of roots and enhance the water absorption capacity of plant roots to resist the damage caused by drought. It was found that under drought stress, the root length and root surface area of maize with exogenous ABA increased significantly compared with that of maize without ABA [33].

3.2 Abscisic acid and salt stress

Salt stress is one of the most common abiotic stresses in plants. At the same time, it is also the main abiotic stress that restricts plant growth and development [34]. Under salt stress, plants grow slowly, plant height is reduced and leaves turn yellow [35], which is similar to drought and water shortage. At present, many studies have shown that there are many signals involved in plant salt stress response [36]. When plants suffer from salt stress, the transcription level and expression of ABA synthesis-related genes are increased, so that ABA content in plants is synthesized in large quantities to adapt to salt stress [37]. In addition, ABA also interacts with JA (jasmonic acid), which plays an important role in the response of plants to salt [38]. ABA can regulate the ion balance inside and outside plant cells and relieve osmotic stress and ion stress caused by high salt concentration [5]. The study on seedlings of *Toona sinensis* showed that the salt stress of external application of abscisic acid could effectively inhibit the absorption of salt ions by plants and enhanced their absorption of other nutrient ions, thus achieving ion balance, alleviating the salt stress inhibition of *T. sinensis* seedlings and resisting the harm of salt stress [39]. At the same time, under salt stress, ABA promotes the production of osmoprotectant in plants, such as proline. Osmotic protectant compounds can maintain osmotic pressure balance and prevent cell plasma wall separation. ABA can also reduce osmotic, ionic, and oxidative imbalances [40]. ABA can enhance the antioxidant defense system of plants, remove excessive ROS by up-regulating the activities of antioxidant enzymes (such as SOD, CAT, POD, etc.), and protect cells from oxidative damage. Related studies showed that the activities of SOD, POD and CAT in tomato seedlings under salt stress for 6 days were significantly lower than those under salt stress with exogenous ABA, which indicated that ABA was involved in scavenging active oxygen and improving the salt tolerance of tomato seedlings [41].

3.3 Abscisic acid and high temperature stress

High temperature stress refers to an abiotic stress that the temperature exceeds the suitable temperature for plant growth and development, thus causesplant damage [42]. High temperature stress will limit plant growth [43], lead to premature senescence and reduce photosynthetic efficiency [44]. Research on high-temperature stress in wild kentucky bluegrasses found that the water content of wild kentucky bluegrasses leaves treated with abscisic acid under high-temperature stress was higher than that without abscisic acid treatment, indicating that ABA can reduce the damage of high-temperature stress to wild kentucky bluegrasses [45]. Under high temperature stress, abscisic acid increases the activity of antioxidant enzymes and removes ROS, thus reducing oxidative damage [46]. Related studies showed that the accumulation of ROS in rice buds with ABA application was significantly lower than that without ABA application, and the content of H_2O_2 was also reduced, and the ROS scavenging genes such as *OsFe-SOD* and *OsCu/Zn-SOD* were significantly up-regulated [47]. This indicates that ABA increases the activity of antioxidant enzymes to clear excess ROS. Exogenous abscisic acid can also promote the synthesis of heat-stable proteins in plants, increase the stability of cell membranes and reduce the damage of high temperature to cell membranes. Abscisic acid can also bind to receptors on the biofilm through signal transduction, increase the stability of the membrane system, and reduce the degree of damage to the cell membrane by high temperature [48].

4. Application prospect of abscisic acid in agriculture

4.1 Agricultural biotechnology strategies

4.1.1 Genetic Engineering

With the continuous development of molecular biology technology, the content of abscisic acid (ABA) in crops can be increased or its ABA signal transduction pathway [49, 50] can be improved by genetic engineering. For example, by overexpressed ABA synthesis-related genes or signal transduction proteins, plants can enhance their tolerance to abiotic stresses such as drought and salt damage, optimize their growth and development processes, and ultimately improve productivity and quality.

4.1.2 Gene editing

In addition to genetic engineering technology, we can also use gene editing technology such as CRISPR-Cas9 to knock out or edit the negative regulatory genes in ABA signaling pathway, and accurately regulate the expression of ABA-related genes, thus improving the stress resistance of plants.

5. Application prospect of abscisic acid in cultivating tolerant plants and improving plant productivity and quality

5.1.1 Cultivate tolerant plants

Abscisic acid plays an important role in plant stress resistance and has broad application prospects in cultivating stress-resistant crops. Controlling the content of abscisic acid by means of genetic engineering and gene editing technology can significantly enhance the tolerance of crops to abiotic stresses such as drought, salinity, low temperature and high temperature, enhance the resistance of crops to abiotic stresses, and provide guarantee for agricultural production. At the same time, abscisic acid can be used to cultivate new crop varieties with specific stress resistance.

5.1.2 Improve crop productivity and quality

Abscisic acid is also of great significance in improving plant productivity and quality. Abscisic acid can participate in regulating the growth and development of plants, such as promoting the development and maturity of seeds and promoting the development of roots, so as to improve the quality characteristics of plants. For example, in fruit tree production, abscisic acid participates in the fruit ripening process, which not only affects the appearance characteristics of the fruit, but also makes the fruit easily detached from the branches and easy to pick [51]. The application of exogenous abscisic acid can promote the regulated synthesis with ethylene and thus promote the ripening of fruits. At the same time, it promotes sugar accumulation and improves the taste and nutritional value of fruits.

6. CONCLUSIONS

This study summarized the discovery, transportation and distribution of abscisic acid, and analyzed the role of abscisic acid in abiotic stress of plants. The application prospect of abscisic acid in agriculture was prospected in order to clarify the importance of abscisic acid in plant resistance to abiotic stress, lay a foundation for the research of plant resistance to abiotic stress, and provide relevant reference for relevant personnel and agricultural producers.

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