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Mini Review

The Flavonoid Bomb: General Metabolic Perceptions in Plants

Hammad Hussain[1*], Hina Shaukat[2], Zainab[2], Hafiza Sarwat Rahman[2]

[1]*Department of Agriculture, Abdul Wali Khan University Mardan (AWKUM), Mardan, Pakistan;* [2]*Department of Biotechnology, Abdul Wali Khan University Mardan (AWKUM), Mardan, Pakistan*

ABSTRACT

The flavonoid pathway is a metabolic pathway in plants that is responsible for the synthesis of flavonoids, which are secondary metabolites that play important roles in plant growth, development, and response to various environmental stresses. This pathway involves a series of enzymatic reactions that convert simple phenolic compounds into complex flavonoid molecules. The genes involved in the flavonoid pathway are regulated by a complex network of transcription factors and signaling pathways that respond to various environmental cues. These genes include structural genes that encode enzymes involved in flavonoid biosynthesis, as well as regulatory genes that control the expression of these structural genes. The study of flavonoid pathway and its related genes is important not only for understanding plant physiology but also for developing new strategies for improving plant growth, enhancing stress tolerance, and producing novel plant based products with potential applications in various fields such as medicine, food, and cosmetics. In this review, we will highlight the existing knowledge and future perspectives of the flavonoid pathway and related genes in plants, which could offer exciting opportunities for further research and development.

Keywords: Flavonoid; Phenylpropanoid pathway; Metabolism; Abiotic stress; Plants

INTRODUCTION

Flavonoids are secondary metabolites found in plants that play an important role in plant survival, growth, and development. They also have antioxidant properties and are beneficial for human health. The flavonoid biosynthesis pathway is a complex process that involves different enzymes, intermediates, and regulatory genes. Flavonoids are synthesized through the phenylpropanoid pathway, which is a branch of the general phenylalanine biosynthesis pathway. The pathway involves a series of enzymatic reactions that convert phenylalanine to flavonoids. The key enzymes involved in the pathway are Phenylalanine Ammonia Lyase (PAL), Cinnamate-4-Hydroxylase (C4H), Coumaroyl CoA Ligase (4CL), Chalcone Synthase (CHS), Chalcone Isomerase (CHI), Flavanone 3-Hydroxylase (F3H), Flavonoid 3'-Hydroxylase (F3'H), Flavonol Synthase (FLS), and Dihydroflavonol 4-Reductase (DFR). The pathway produces various flavonoids, such as anthocyanins, flavanols, flavones, isoflavones, and flavonols. The regulatory genes are responsible for controlling the expression of biosynthetic genes and enzyme activities. The MYB, bHLH, and WD40 transcription factors are the key regulators of the flavonoid biosynthesis pathway. These transcription factors interact with each other to form a complex regulatory network that controls the synthesis of different flavonoids [1].

Flavonoids play an important role in plant development, survival, and defense mechanisms against various biotic and abiotic stresses. Moreover, flavonoids have health benefits for humans and are widely used in the pharmaceutical, nutraceutical, and cosmetic industries. The understanding of the flavonoid biosynthesis pathway and the related genes is crucial to develop new strategies for improving the yield and quality of flavonoids in plants. The genes regulating the pathway are highly conserved in plants and are referred to as the Flavonoid Biosynthesis Genes (FBSGs). Top date, the FBSGs have been identified and characterized in various plant species. The regulation of the biosynthesis pathway is also influenced by environmental factors, such as light and temperature. Several pharmacological properties of flavonoids have been associated and are widely used in the pharmaceutical industry [2-5]. They have anti-inflammatory, anti-cancer, anti-tumor, and anti-

Correspondence to: Hammad Hussain, Department of Agriculture, Abdul Wali Khan University Mardan (AWKUM), Mardan, Pakistan; E-mail: hammadagarian@gmail.com

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diabetic properties, and also help in reducing cardiovascular diseases. The flavonoid biosynthesis pathway plays a vital role in the production of flavonoids with these pharmacological properties. The enzymes involved in the pathway can be manipulated to produce flavonoids with desired pharmacological properties.

Abiotic stresses such as drought, cold, heat, and salt adversely affect plant growth and development. The flavonoid biosynthesis pathway has been shown to play a role in abiotic stress responses in plants. The accumulation of flavonoids in plants during abiotic stress is thought to protect the plants from oxidative damage caused by Reactive Oxygen Species (ROS). Flavonoids act as antioxidants and scavenge ROS to reduce oxidative damage in plants. The flavonoid biosynthesis pathway may also play a role in the regulation of gene expression during abiotic stress responses. The expression of flavonoid biosynthesis genes is induced by abiotic stresses, indicating their involvement in stress response pathways in plants. They also help in regulating the plant's hormonal balance and improving the plant's growth and development under stress conditions. Thus, the flavonoid biosynthesis pathway is likely to play a significant role in the abiotic stress responses of plants, and manipulating the pathway's enzymes can help in enhancing the plant's tolerance to abiotic stresses.

LITERATURE REVIEW

Flavonoids interacting plant world

Plants respond to abiotic stresses, such as drought, salinity, and extreme temperatures, by producing secondary metabolites, including flavonoids. Flavonoids act as antioxidants and help in protecting plants from oxidative stress caused by abiotic stress. They also help in regulating the plant's hormonal balance and improving the plant's growth and development under stress conditions. Previous studies on *Arabidopsis* model plant have been extensively studied for important roles of flavonoid in regulating abiotic stress responses and growth related activities. Significant advancements have been made in our understanding of the regulation of the flavonoid pathway and the functional roles of various flavonoid pathway genes in Safflower (*Carthamus tinctorius*). It is an important medicinal plant with several pharmacological properties, and it is widely used in Chinese traditional medicine for the treatment of various ailments [6,7]. The flavonoids present in safflower have anti-inflammatory, antioxidant, and anticancer properties. Several studies have been conducted to elucidate the flavonoid biosynthesis pathway and related genes in safflower, with a view to enhancing the yield of flavonoids for medicinal purposes. These recent studies have shed light on the molecular mechanisms underlying flavonoid biosynthesis and regulation, and provide new insights into the potential applications of flavonoids in crop improvement and human health [8].

Flavonoids as key players in stress responses and floral pigmentation

Flavonoids play a critical role in the antioxidant defense system in plants by scavenging free radicals, regulating the activity of antioxidant enzymes, chelating metal ions, and modulating gene expression. All these mechanisms work together to protect plant cells from oxidative damage caused by biotic and abiotic stress. They act as potent antioxidants that can quench free radicals and Reactive Oxygen Species (ROS) in plants. This property of flavonoids allows them to protect plant cells from oxidative damage, which can be caused by biotic and abiotic stresses. In addition, flavonoids are known to regulate the activity of several antioxidant enzymes such as Superoxide Dismutase (SOD), Catalase (CAT), and Peroxidase (POD). They do so by increasing the expression of genes that encode these enzymes, which enhances their activity in plant cells. Chelate metal ions such as Iron (Fe) and Copper (Cu), which are known to trigger the production of ROS in plants. By chelating these metal ions, flavonoids reduce the formation of ROS and protect plant cells from oxidative stress. Furthermore, flavonoids have been shown to modulate the expression of genes that are involved in the antioxidant defense system in plants. They can activate the expression of genes that encode antioxidant enzymes and decrease the expression of genes that promote ROS production.

Flavonoids are the precursors of anthocyanins, which are water soluble pigments that give plants their red, purple, and blue colors. Flavonoids can regulate the synthesis of anthocyanins by controlling the expression of genes encoding enzymes involved in anthocyanin biosynthesis. They can also act as co-pigments, which mean that they can enhance the color intensity of anthocyanins by forming stable complexes. Flavonoids can also regulate the synthesis of pro-anthocyanidins, which are complex flavonoids that contribute to the brown color of some plants. Flavonoids can control the expression of genes encoding enzymes involved in proanthocyanidin biosynthesis, leading to the formation of different types of proanthocyanidins. This mechanism allows plants to produce a wider range of colors [9,10]. Similarly, flavonoids can absorb UV radiation, which can be harmful to plant cells. The absorption of UV radiation by flavonoids protects plant tissues by preventing DNA damage and reducing oxidative stress. Flavonoids can stabilize the membrane structures of plant cells, which can help plants cope with abiotic stresses such as extreme temperatures and drought. They can regulate the expression of genes encoding antioxidant enzymes, such as catalase, superoxide dismutase, and peroxidase, which can enhance the antioxidant defense system of plants. Flavonoids can also increase the production of non-enzymatic antioxidants, such as ascorbic acid and glutathione. Some flavonoids and their types, such as flavonols and isoflavones, can induce the expression of stress responsive genes in plants, which can help plants cope with abiotic stresses. Different classes of flavonoids can also regulate the transport of ions, such as calcium and potassium, in plant cells, which can help maintain ion homeostasis and protect plants from abiotic stresses such as salt stress [11].

DISCUSSION

Flavonoids can act as phytoalexins, which are antimicrobial compounds that plants produce in response to pathogen attack. Flavonoids such as isoflavonoids and flavones have been shown to have antimicrobial activity against a wide range of pathogens. For example, flavonoids such as anthocyanins have been shown to upregulate the expression of genes involved in defense signaling pathways and pathogenesis related proteins. The types of flavonols and flavones have been shown to deter feeding by insect herbivores and attract beneficial insects such as pollinators and natural enemies of plant pests [12]. Flavonoids can induce systemic resistance in plants, which is a form of plant defense that provides long lasting protection against a wide range of pathogens. Flavonoids such as quercetin have been shown to induce systemic resistance in plants by priming defense responses and enhancing the expression of defense related genes. Similarly, various phytohormones have been also demonstrated to play synergistic roles with flavonoids. For example, Abscisic Acid (ABA) is a stress hormone that is known to regulate flavonoid synthesis in response to abiotic stresses such as drought and salinity [13]. ABA can upregulate the expression of genes encoding enzymes involved in flavonoid biosynthesis, leading to increased flavonoid accumulation in plants. Similarly, Jasmonic Acid (JA) and Salicylic Acid (SA) are hormones that play important roles in regulating flavonoid synthesis during biotic stress responses. JA can induce the expression of genes encoding enzymes involved in flavonoid biosynthesis, leading to increased flavonoid accumulation in plants. SA, on the other hand, can downregulate the expression of genes encoding enzymes involved in flavonoid biosynthesis, leading to decreased flavonoid accumulation in plants [14].

Unlocking genome editing tools for flavonoids biosynthetic suits

Flavonoid biosynthetic pathway and its related genes have tremendous potential for genome editing applications in plants. The pathway plays a crucial role in the biosynthesis of flavonoids, which are well-known for their diverse biological and coloring properties. The genes involved in flavonoid biosynthesis are mainly regulated by a complex network of transcription factors, biosynthetic enzymes, transporters, and other regulatory genes. The recent advancements in genome editing technologies such as CRISPR/Cas systems have enabled precise and efficient modifications of plant genomes. The flavonoid pathway has emerged as a promising target for improving plant phenotypes, such as enhanced abiotic and biotic stress tolerance, improved nutritional value, and increased yield potential [15]. One of the major applications of genome editing in the flavonoid pathway is to enhance the production of flavonoids. Flavonoids are important secondary metabolites with numerous health benefits and play a significant role in plant defense against various biotic and abiotic stresses. Genome editing can be utilized to increase the yield and quality of flavonoids in crops, thus making them more nutritious and healthier [16]. For example, the overexpression of key genes involved in flavonoid biosynthesis has been shown to enhance the production of flavonoids in various plant species. Additionally, the flavonoid pathway can also be targeted to improve plant resistance against various biotic and abiotic stresses. Studies have shown that flavonoids can act as potent antioxidants and play a critical role in protecting plants against oxidative stress induced by environmental factors such as UV irradiation and heavy metals. Genome editing can be used to modify the flavonoid biosynthetic pathway to enhance the production of specific flavonoids that possess superior antioxidant properties [17]. In conclusion, the flavonoid biosynthetic pathway and its related genes have immense potential for genome editing applications in plants [18]. The pathway plays a crucial role in the production of flavonoids, which have diverse biological and coloring properties. Genome editing can be utilized to enhance the production of flavonoids, improve plant resistance against various biotic and abiotic stresses, and increase crop yield potential [19-23].

CONCLUSION

The study of flavonoid pathway and its related genes is important not only for understanding plant physiology but also for developing new strategies for improving plant growth, enhancing stress tolerance, and producing novel plant based products with potential applications in various fields such as medicine, food, and cosmetics. In recent years, there has been an increasing interest in developing plant based therapies using flavonoids. Future research should focus on identifying new compounds of flavonoids with potential therapeutic effects and optimizing their production in plants. Similarly, future the discovery of new flavonoids compounds and its derivatives can play essential part in enhancing plant resistance to stress, and to develop strategies for engineering plants with increased flavonoid content. Future researches could also aim to identify new flavonoids that can improve plant growth and development to improve yield and productivity of important agronomic crops. Flavonoids have a wide range of industrial applications, including food, cosmetics, and pharmaceutical industries and hence more efforts are needed to harness new possibilities of flavonoids with potential industrial applications, as well as develop strategies for optimizing their production in plants.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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