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Research progress and prospect of grape fruit coloration

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Abstract
The appearance and color of grapes is one of the most important quality characteristics, and the beautiful color and uniform color of grapes are often favored by consumers. In this paper, the research progress related to grape fruit coloring in recent years was summarized, and the external environment such as light, temperature, water and so on which affected grape fruit coloring was mainly reviewed, in order to provide some guidance for high-quality grape production.

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1. Introduction

The grape (*Vitis vinifera* L.) is a woody vine that ranks second in both fruit production and cultivation area in the world today [1]. Grape skin color is one of the important commodity attributes of grapes, which directly affects the price and competitiveness of fruits in both table grapes and wine grapes. In recent years, grape fruit coloring has been extensively studied and great progress has been made. Scholars have studied the influencing factors of grape fruit from different angles, from changing the external growing environment of grapes to using plant growth regulators to implementing various cultivation and management measures. Through the influence of different factors, the changes of grape from macroscopic physiological phenotype to microscopic gene level were analyzed, and many effective methods for improving grape fruit coloring were obtained, which also laid a solid foundation for further research on grape fruit coloring.

For grapes, fruit color is not only affected by genotype, but also by external environmental conditions (such as light, temperature, water, etc.), a variety of endogenous and exogenous plant growth regulatory substances, and a variety of signals interact with, or cooperate or antagonize, through complex regulatory networks to jointly cause transcription and expression of genes related to anthocyanin biosynthesis, and ultimately achieve changes in grape fruit color.

2. Light

Environmental factors have important effects on the synthesis of anthocyanins, especially the effect of light. After receiving light stimulation through photoreceptors, plants transmit the signal to transcription factors, and then use transcription factors to spatio-temporal expression of structural genes in anthocyanin synthesis pathway. Light can activate photochromes and promote the synthesis or activation of enzymes, while shading treatment can reduce the content of anthocyanins. The results show that light can significantly improve the enzyme activities of PAL, CHS, DFR and UFGT, thus promoting anthocyanin accumulation. The expression of peach MYB10 and grape VvMybPA1, VvMyb14, VvMyb4 can promote the synthesis of fruit anthocyanins [2]. Shading treatment can affect the synthesis of anthocyanins and the expression of transport-related genes, thus reducing the content of anthocyanins and changing their components.

Under light conditions, the content of anthocyanins increases rapidly, indicating that light has a positive regulatory effect on the accumulation of anthocyanins in grapes. Exposure and shading treatment of grape ears of "Cabernet Sauvignon" promoted and inhibited the expression of PAL2, PAL4 and PAL7 and the accumulation of corresponding phenolic substances, respectively. According to correlation analysis, there was a significant correlation between the expression of PAL2, PAL4 and PAL7 and phenolic components under different lighting conditions. These three PAL genes play a key role in photoregulation of the metabolism of phenolic substances in grape fruit. In terms of light quality, studies have shown that ultraviolet (UV), blue light, infrared light and far infrared light can improve the activities of key enzymes in anthocyanin synthesis to varying degrees, such as UV-A treatment can improve the activities of PAL and CHS, and promote anthocyanin accumulation. The positive effects of UV-B on the ripening of grape berries increased the content of anthocyanins in the berries. In different wavelengths of light, the effect of ultraviolet light was the strongest. With the increase of altitude and the enhancement of ultraviolet light, the colorability and colorance of fruit were significantly increased. Blue and red LED light treatment at night can increase the content of anthocyanins in grape peel, and blue LED light treatment can effectively increase the concentration of anthocyanins and sugar in grape peel; In addition, it was also found that the ABA concentration in the peel treated with red LED light was the highest, and the anthocyanin concentration in the peel treated with red LED light was lower than that in the peel treated with blue LED light, indicating that anthocyanin synthesis was not only related to ABA concentration, but also related to sugar concentration in the peel. Through transcriptomic analysis, the genes that may play an important role in the response and transmission of grape light signal (HY5, UVR8, PHY, CRY and COL) and the transcription factor genes that may be involved in the regulation of photo-induced anthocyanin accumulation in grape were selected (MYB, bHLH, NAC and ERF) [3]. At present, the regulatory mechanism of photoinduced anthocyanin synthesis is not very clear, and further studies are needed.

3. Temperature

Temperature is a key environmental factor affecting grape fruit coloring. Relevant studies have confirmed that anthocyanins are unstable. As the temperature increases, the half-life decreases. Rapid cooling after high temperature can indirectly affect the enzyme activity related to anthocyanin synthesis. Under the condition of high temperature, the activity of enzymes related to anthocyanin synthesis is reduced, which has an inhibitory effect on its synthesis, thus affecting its stability and significantly reducing the concentration of anthocyanin. Appropriate low temperature can promote the expression of structural genes in anthocyanin synthesis pathway, while too low temperature can inhibit the synthesis. High temperature (30~35°C) can reduce the content of anthocyanins in grape fruits. High temperature induced ABA accumulation and MybA1s expression in grape fruits, while the expressions of anthocyanin synthesis-related genes UFGT, OMT and F3'5'H were inconsistent with those of MybA1s at different temperatures, suggesting that MybA1s had a different mechanism in grape fruit temperature response to up-regulate anthocyanin synthesis. High temperature and intermittent high temperature treatment can significantly inhibit the anthocyanin synthesis-related gene MybA2, thus inhibiting the fruit coloring and anthocyanin accumulation of "Jufeng" grape. However, the ABA/GA ratio of grape fruits treated at high temperature and intermittent high temperature was different, suggesting that the color of grape skins and anthocyanin synthesis might be related to the ABA/GA ratio. In addition, the temperature cycle also had a certain effect on the synthesis of anthocyanins in grape. A suitable temperature difference between day and night (30°C during the day and 15°C at night) was conducive to the synthesis of anthocyanins in grape, while a higher night temperature (such as 30°C) would reduce the activities of CHS, F3H, DFR, UFGT and other enzymes and reduce the synthesis amount of anthocyanins [4]. This may be due to the low temperature at night will inhibit the respiration of the fruit and leaves, so that the sugar content in the fruit increases, and the synthesis of anthocyanins cannot be separated from the participation of sugar, thus promoting the synthesis of anthocyanins in the fruit.

4. Moisturee

Water condition is one of the factors that determine the yield and quality of grape fruit. Studies have shown that water deficits consistently increase anthocyanin concentrations by increasing the content of each berry and reducing fruit growth. Anthocyanin biosynthesis is strongly up-regulated in mature grapes grown under drought conditions, which can promote the expression of CHS2, CHS3, F3H, F3'5'H, OMT genes related to anthocyanin biosynthesis [5]. Drought stress can cause anthocyanin methylation in grape berries. VvCCoAOMT has been shown to contribute to anthocyanin methylation under drought stress. The study found that proanthocyanidins B2, B4+B3 are usually increased by insufficient water, and several other MYB TFs are strongly regulated by dehydration. VviMYB14, VviMYB15, VviMYB5B, VviMYBA1, VviMYBC2-L1 and VviMYBPA1 are involved in regulating the phenylpropane metabolic pathway [6]. In general, the expression period of different genes under water stress was different. Mild water stress was the best, and severe water stress would reduce fruit quality and anthocyanin content.

5. Looking forward

Grapes are widely loved by consumers in the international market, with great economic value and development potential. The appearance color of grape fruit is the first impression to consumers, which determines its commodity value to a large extent, so it is of great significance to study the related issues of grape skin coloring. Anthocyanin synthesis is a continuous process, and problems in any link will lead to changes in anthocyanin content. Therefore, in the future, when we continue to pay attention to the external environment, we also need to pay attention to the changes and effects of other factors on anthocyanin content.

To put it simply, the quality of grape fruit coloring depends on the corresponding anthocyanin content in the peel, and anthocyanin synthesis is directly controlled by structural genes, transcription factors can regulate the expression of structural genes, and various external factors can affect the endogenous hormone level and nutritional conditions of plants, and different signals can stimulate the change of the expression level of related genes. Finally, the content of anthocyanins was changed. At present, the research on grape fruit coloring mainly focuses on detecting the change of

anthocyanin content after stimulation by external factors, detecting the change of related gene expression at the molecular level, or observing the change of macro anthocyanin content after overexpression or inhibition of related genes, while there are few studies on various subtle synthetic regulatory mechanisms inside the fruit. There are still many unanswered questions in research related to grape fruit coloring, Such as the mechanism of action of regulatory genes, the synergistic mechanism between different signal molecules, various signal transmission pathways, intracellular transport mechanism of anthocyanins, the formation and regulatory mechanism of MYB-bHLH-WD40 complex, the positive and negative feedback regulatory mechanism in anthocyanin synthesis, and how to effectively enhance positive regulation. Inhibition of negative regulation to improve anthocyanin synthesis intensity, how to effectively improve the expression level of key enzymes in anthocyanin synthesis pathway, fruit tree breeding and germplasm creation with peel color (peel anthocyanin content) as the main target trait, etc. Well-colored grapes have significant competitive advantages among similar products. More importantly, the rich anthocyanins they contain have great benefits to human health. Therefore, it is of great significance for the grape industry to thoroughly clarify the regulatory mechanism of grape anthocyanin synthesis and research and develop effective methods for grape fruit coloring.

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