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Review Paper

The Role of Environmental Factors and Plant Growth Regulators on Grapes Coloration

Raed S. Shehata[1]

[1] Department of Agriculture, Ministry of Agriculture and land reclamation, Damanhour, Egypt.

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Corresponding Author
raedsalem8882001@gmail.com

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Abstract

Grapevine is the world's commercial horticulture crop. Poor coloration of grapes is one of the problems in grape production. Climate changes could negatively affect grape quality by reducing color formation. The effect of high temperatures on anthocyanin content and composition in the main red-producing grapes would help estimate their phenotypic change and perhaps predict whether they will be able to sustain the attributes of high-quality grapes in the context of climate change. Climate changes played an important role in lack sufficient berry color especially high temperature inhibited L-phenylalanineammonialyase (PAL). L-phenylalanineammonialyase improved accumulation of anthocyanin in the skin of grape berries. Environmental factors like light, temperature and irrigation are effective in either grapes coloration or discoloration. Plant growth regulators like Brassinosteroids (BRs), Jasmonic acid (JA), Salicylic acid (SA) and Abscisic acid (ABA) are accelerating the accumulation of anthocyanin in grapes berry skin. So it is very important to know how grapes coloration, the effect of plant growth regulators and environmental factors on grapes coloration.

Introduction

An important perennial crop grown in many countries is grapevine mainly for wine production, but also for table grapes and raisins (Alston and Sambucci, 2019). The main components that determine the composition of grape berries are sugars, organic acids, and various secondary metabolites such as tannins, flavonols, anthocyanins, aroma precursors, and volatile compounds, which is significant for grape growers (Conde et al., 2007). The maturation process is influenced by both external and internal factors such as temperature, light, phytohormones, and plant water status (Gao-Takai et al., 2017; Sugiura et al., 2018; Azuma, 2018). Anthocyanins accumulate into the skin of grape berries due to a variety of environmental stimulation, such as developmental signals, environmental stresses such as (light, irrigation, temperature, etc.), and plant growth regulators (Boss and Davies, 2009). Because well-pigmented grapes are often preferred by customers, skin color is a crucial characteristic that serves as the foundation for selection in breeding projects. Farmers appreciate these fruits' great marketability so, The skin color of berries is determined by the composition and quantity of anthocyanins. By altering the expression of genes involved in the anthocyanin biosynthesis pathways plant growth regulators can be used to improve the color of red grapes even at low concentrations of these compounds. From veraison until harvest anthocyanin biosynthesis and accumulation in skin cells occur primarily under genetic control (Costantini et al., 2015; Gagné et al., 2011).

This review observed that recent studies of plant growth regulators and environmental factors on The regulation of anthocyanin production in grape berry skin to give growers a workable and practical regime for producing grape clusters with high quality.

Enviromental Factors Affecting on Grapes Coloration:

Light

According to Matus et al. (2009), exposure to light is a significant factor that affects grape coloration through the up-regulation of several genes including those involved in the biosynthesis of anthocyanins. The amount of light that reached the berries was correlated with the color of the clusters (Ma et al., 2019). Plant cells absorb light through phytochromes or photoreceptors which are then used by a number of metabolic pathways within the plant. PAR or photosynthetically active radiation is the 400–700 nm solar radiation range that plants can use for photosynthesis the process of turning light energy into usable energy. Each wavelength in the white light spectrum which spans from 380 nm to 780 nm, is received by phytochromes in plant cells and serves a distinct purpose (Demotes-Mainard et al., 2016). According to Cheng et al. (2015), grape berries' anthocyanin content is enhanced when they are exposed to blue light which is achieved by covering the greenhouse with blue plastic film. According to Cohen et al. (2012), berries heated to 20.5°C and cooled to ±8°C changed the initial rates of proanthocyanidin accumulation. On the other hand, the total proanthocyanidin accumulation appears to be more dependent on the development of berries during a specific season than it is on the thermal time. By modifying the expression of genes affected in the flavonoid biosynthesis pathway, cultivar, temperature, and light conditions can also assess the anthocyanin content in grape skin (Azuma et al., 2012). Light exclusion reduces the concentration and modifies the composition of grape anthocyanins by altering the expression of genes involved in the process of anthocyanin biosynthesis and transport in a cultivar and tissue specific manner (Guan et al., 2016). Numerous viticulture practices have been employed in previous studies on light exposure and cluster shading. Some of the techniques utilized are the use of plastic netting (Chorti et al., 2010), shade cloths (Caravia et al., 2016; Greer and Weedon, 2013), and some leaf removal techniques surrounding the grape cluster (Lee and Skinkis, 2013; Chorti et al., 2010). (Guan et al., 2014) demonstrated that as anthocyanins accumulated during berry ripening the skin's ability to transmit light decreased. As a result, the berry flesh’s shading effect is enhanced by the colored skin.

Temperature

Climate change related high temperatures and decreased precipitation lead to advanced maturation which balances grape sugars and phenolic maturity and impacts grape composition (Poni et al., 2018). Farag et al, (2012) observed that, in comparison to non-dissipation accumulation heat, ethrel formulation at (400 ppm) in the presence of ethanol at (5%) at 15–20% berry coloration improved berry color and quality of "Crimson Seedless" grapes at harvest. According to Farag et al. (2011) in order to prevent accumulation of heat it is recommended to apply EDTA or ethanol two safe chemicals, under an open canopy in between rows of "crimson" seedless vines in order to increase the effectiveness of ethylene at 400 ppm. During ripening high temperatures (HT) typically suppress the anthocyanin accumulation that gives grape berries their color while low temperatures encourage it (Shinomiya et al., 2015). One of the major environmental factors regulating a cultivar's anthocyanin profile is temperature (De Rosas et al., 2017). Knowing the molecular mechanisms underlying temperature's effects on grape coloration during ripening is crucial because summertime HTs may reduce the color of wine and table grapes by inhibiting the biosynthesis of anthocyanins in grape berries (De Orduña, 2010; Barnuud et al., 2014; Fraga et al., 2012). Temperature is possibly the environmental factor that affects anthocyanin accumulation in grapes the most (Jones et al., 2012). According to a recent study by Gaiotti et al. (2018), A single season of the two seasons saw an increase in anthocyanin accumulation in grapes exposed to cool night temperatures (10–11°C, as compared with 15–20°C in the control) from 12 days before veraison until the end of veraison. Temperature regimes also had an impact on the composition of anthocyanins. High temperature treatments increased the proportion of acylated and methoxylated anthocyanins (De Rosas et al., 2017). According to recent research, flavonol accumulation was negatively impacted by high temperatures (30–40°C) during the berry ripening process (Degu et al., 2016; Pastore et al., 2017). According to Gaiotti et al. (2018) and industry anecdotal information grape flavonoid concentration is influenced by variations in day and nighttime temperatures with larger variations favoring flavonoid concentration. The fact that nighttime temperatures have increased more quickly than daytime temperatures over the past 50 years due to climate change makes this topic even more crucial today and points to future years of declining day-to-night temperature differences (Stocker et al., 2014). In particular, it was discovered that high temperatures in some cultivars altered the physiology and chemical composition of the berries as well as reducing their color (Sadras and Petrie, 2011). Furthermore, red wines made from the cultivars Barbera and Croatina were found to have lower resveratrol contents when fruit ripened at high temperatures (Rocchetti et al., 2021).

Irrigation

It has been discovered that irrigation of vineyards impacts the biosynthesis of phenolics, which is a common practice in arid and semi-arid regions of the world (Cohen and Kennedy, 2010). When water stress or limitation occurs (i.e., before or after veraison). 'Crimson Seedless' coloration is being improved by post-veraison regulated deficit irrigation (RDI) techniques (Faci et al., 2014).

Grapevine productivity may be restricted by the distribution of rainfall and water availability, particularly towards the end of the growth cycle (Fraga et al., 2016, 2018). Different management practices like deficit irrigation (DI) can help to increase water use efficiency (WUE) maintain or improve wine quality and stabilize yield (Lanari et al., 2014; Galvez et al., 2014; Bonada et al., 2018; Cole and Pagay, 2015). The synthesis and concentration of phenolic compounds, soluble solids, and anthocyanins were observed to be enhanced by water scarcity (Degaris et al., 2015; Ferrandino and Lovisolo, 2014; Conesa et al., 2016). In contrast to rain fed vineyards Zarrouk et al. (2016) found lower levels of anthocyanins in the grape skins and less color in the wines. As a result of an increase in the berry's skin to pulp ratio. Bindon et al. (2011) claim that the benefits of water deficit in grapevines are directly linked to elements of wine quality such as color, flavour, and aroma. By promoting anthocyanin hydroxylation a water deficit can increase the accumulation of anthocyanins (Chaves et al., 2010). According to Romero et al. (2010), cv. Monastrell grapes exhibit a total grape phenolic compound concentration that is correlated with severe water stress. But according to a recent study Casassa et al. (2015), Cabernet Sauvignon grape varietals and wines with higher phenolic compound concentrations were produced when early and complete deficit irrigation was applied prior to veraison. Generally, red grapes with mild water stress have higher concentrations of these substances which enhances berry quality. Unfortunately these beneficial effects are reported to decrease once a specific level of water stress occurs (Romero et al., 2010). In a similar vein, Delgado Cuzmar et al. (2018) report that using less water can improve the chemical and sensory quality of wine. This is noteworthy given the possibility of declining water supplies due to climate change. According to Niculea et al. (2015), The concentration and content of phenolic compounds in response to extended deficit irrigation differ based on the type of berries that are developing and maturing. In comparison to the rain fed regime, the yield was significantly increased by the deficit irrigation (DI) and fully irrigated (FI) strategies, which improved vine water use by 18% and 27% respectively (Ramírez-Cuesta et al., 2023). Deficit irrigation (DI) is a technique that can assist modify the gap between technological and phenolic maturity in the context of the rain-fed technique, enhancing vine performance and production (Pérez-Álvarez et al., 2021).

Plant Growth Regulators Affecting on Grapes Coloration:

Brassinosteroids (BRs)

The sixth-largest phytohormone was found to be BRs, a sterol phytohormone, because of its beneficial effects on plant growth and stress resistance, even at extremely low concentrations (Sun et al., 2020). Vergara et al. (2018) state that exogenous applications of various BRs analogues to "Redglobe" grape clusters cause a notable change in the distribution of anthocyanin groups additionally to an increase in the color, soluble solids content, and total anthocyanins of the berries. Accordingly, Li et al. (2022) found that preharvest exogenous administration of 100 mmol. L^{-1} jasmonic acid and 0.5 mg.L^{-1} 2,4-epibrassinolide was an effective means of enhancing grape berry quality. The impact of exogenous BR applied to Cabernet Sauvignon clusters at a concentration of 0.4 mg/l on anthocyanin accumulation and anthocyanin biosynthesis gene expression (Xi et al., 2013 and Luan et al., 2013). Previous research found that pre-harvest administration of 2,4-epibrassinolide at 0.4 and 0.6 mg.L^{-1} significantly boosted proanthocyanidin accumulations and accelerated the metabolism of soluble sugars in the Cabernet Sauvignon and Merlot grapes, respectively (Xu et al., 2015; Yan et al., 2022).

Jasmonic acid (JA)

Jasmonates (JAs) which are composed of methyl jasmonate (MeJA) a volatile derivative of jasmonic acid are thought to function as hormones in plants influencing several physiological functions, including growth, photosynthesis, reproductive development, and responses to biotic and abiotic stresses (Dar et al., 2015). According to reports, JA is crucial for causing stomatal closure, blocking Rubisco biosynthesis, impacting the absorption of N and P as well as the transportation of glucose and other organic compounds (El-kenawy, 2018; Gomi, 2020). Previous research has shown that MeJA treatments to vineyards increased the phenolic content, primarily anthocyanins, flavonols, and stilbenes on grape and wine, despite significant variations in the growing season and varieties (Gómez-Plaza et al., 2017; Portu et al., 2015, 2016, 2018). According to Flores et al. (2015), an evaluation of postharvest MeJA treatment revealed an increase in the 'Red Globe' cultivar's total phenolic and anthocyanin concentrations as well as antioxidant activity. Studies demonstrated the enhancement of anthocyanin and other polyphenolic compounds in grapevines and wines through the application of MeJA treatments (Portu et al., 2015, 2016; Gil-Muñoz et al., 2017). M.E. García-Pastor et al. (2019) Demonstrate that MeJA 1mM treatments enhanced the total phenolic concentration at harvest by 1.3 and 1.5 times, respectively in 'Crimson' and 'Magenta' cultivars during 2016 experiment. Similarly, MeJA treatments were found to increase the concentration of phenolics during 2017 experiments in both cultivars at 0.1 mM was the most effective concentration. MeJA is currently applied directly to grapevines more frequently due to its positive effects on the synthesis of phenolic compounds in grapes (D'Onofrio et al., 2018). In particular, the anthocyanins, flavonols, and stilbenes in "Graciano" and "Garnacha" rose in the grapes after MeJA treatment (Portu et al., 2018; Portu et al., 2017). The amount of phenolic compounds in grapes after MeJA treatments differs mostly based on the response of the variety and the climate of the season (Portu et al., 2018; Gil-Muñoz et al., 2017).

Salicylic acid (SA)

Ortho-hydroxyl benzoic acid, also known as salicylic acid (SA), is a phenolic naturally occurring plant growth regulator that is categorised as a growth promoter. According to Hayat et al. (2010), it has been discovered to be important in controlling plant growth, development, and vigour under both abiotic and biotic stresses. An effective agronomic method to produce table grapes with improved health-promoting properties is by spraying grapevines with exogenous salicylic acid (Champa et al., 2015). Salicylic acid (SA) to postpone the ripening of "Superior Seedless" grape fruit clusters (Lo'ay, 2017). By reducing the activity of the enzymes that break down cell walls ascorbic acid at (6 mM) and salicylic acid at (4 mM) treatments prevented fruit cluster deterioration during shelf life while preserving phenolic compounds. According to Abdelaziz et al. (2022), the application of exogenous potassium silicate plus (SA) at 100 ppm showed to be the most successful treatment in maintaining the general quality of grapes that were stored. According to Champa et al. (2015), during cold storage the "Flame Seedless" cultivar's berry color, firmness, phenolic content, and organoleptic characteristics were all preserved by exogenous

SA at 1.5 and 2 mM. Furthermore, SA foliar application at the pre-veraison stage of 'Sahebi' grapes increased the concentration of anthocyanins at harvest particularly malvidin-3-glucoside the major anthocyanin in this cultivar as well as total phenolics and flavonoids (Oraei et al., 2019). Chen et al. (2006) found that after harvesting whole "Cabernet Sauvignon" berries in vivo infiltration of 150 _M SA activated PAL by increasing PAL mRNA accumulation the synthesis of a new PAL protein and enzyme activity. The increased total phenolic concentration observed in berries from treated vines could also be attributed to the effects of salicylate treatment on PAL activity. Salicylate pre-harvest treatments would therefore increase antioxidant properties and health beneficial effects of table grape consumption, given the established role of phenolic compounds, including anthocyanins, in health beneficial properties (Xia et al., 2010; Flamini et al., 2013; Blanch et al., 2020). MeSa exogenous at 0.1 mM may increase bioactive compounds in table grapes that have antioxidant qualities which could improve the grapes' health benefits. Additionally, it could accelerate up the ripening process of grapevines and maintain qualitative characteristics throughout a long period of storage, according to (García-Pastor et al., 2020).

Abscisic acid (ABA)

It is generally accepted that abscisic acid (ABA) naturally occurs in grape skins at the start of ripening, when the concentration of anthocyanins and other phenolic compounds also increases. It is in charge of anthocyanin production in grape berries (Boss et al., 1996a, b; Kobayashi et al., 2002). Although the UFGT gene is found in all grape varieties only red-colored cultivars express it (Boss et al., 1996b). Exogenous antagonist (S)-cis-abscisic acid (S-ABA) has been demonstrated in a number of applications to successfully increase the anthocyanin concentration in grape skin in previous studies. (Roberto et al., 2012, 2013; Koyama et al., 2014, 2019; Yamamoto et al., 2015; Domingues Neto et al., 2017). The use of S-ABA at the right concentration and time is essential for improving grape skin color development and these may differ based on the cultivar and application area (Peppi et al., 2006, 2007, 2008a). By initiating the biosynthesis of anthocyanins, the application of S-ABA at different phases of grape maturation increases the amount of secondary metabolites in grapes, explaining the increase in anthocyanin (Tecchio et al., 2017). The application of S-ABA during pre- and veraison may have contributed to the rise in anthocyanin contents of 'Benitaka' table grapes. During the early stages of ripening, grape tissues are more susceptible to ABA stimulation for anthocyanin processing (Yamamoto et al., 2015). At the start of veraison ABA is crucial in controlling several genes including those connected to the signaling pathway and stimulation of anthocyanins (Gambetta et al., 2010). The "Isabella" grapes' anthocyanin contents and color were considerably enhanced by the foliar application of S-ABA at pre-veraison and post-veraison followed by a second application (Yamamoto et al., 2015). In table grapes, a single utilization of S-ABA results in a poorer grape color than multiple applications (Roberto et al., 2013).

Additionally, applying S-ABA at pre-veraison and veraison produced the best results. The accumulation of anthocyanin in the skin of grape berries has been suggested to be caused by sugars and ABA levels, which activate the gene expressions involved in anthocyanin production (Keller, 2015). The efficiency of the berries is increased when exogenous S-ABA is added around the time of veraison when the genes are already active. Prior research on "Crimson Seedless" revealed that the treated grapes' UFGT levels dropped three weeks after S-ABA was applied (Peppi et al., 2008b). Vanillylacetone increased the expression of genes that produced endogenous ABA which accelerated the biosynthesis of anthocyanins and caused The accumulation of grape berry anthocyanins in the skin (Enoki et al., 2017). According to Gagné et al. (2006), After véraison, endogenous ABA content rapidly increased and accelerated the ripening of grape berries, including the production of anthocyanins (Pilati et al., 2017). Farag et al. (2018) suggested that using the composition containing lysophosphatidylethanolamine (LPE) commerical name (lisophos 70%) at 400 ppm plus magnesium nitrate at 1% (w/v) as well as Abscisic acid (ABA) comerical name (ProTone 10%) at 200 ppm to accelerate veraison and improve the "Crimson seedless" grapevine's berries quality under field conditions.

Conclusion

Previous review observed that the environmental factors and plant growth regulators are more effective in influencing grapes coloration and also provide grape producers with feasible and applicable regime to produce high quality grape clusters.

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Conflicts of interest

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