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Effect of plant bioregulators on colour development in table varieties of grapes (*Vitis vinifera* L.)

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Abstract

The study entitled “Effect of Plant Bioregulators on Colour Development in Table Varieties of Grapes (*Vitis vinifera* L.)” was conducted at MPKV, Rahuri (Oct 2024-Mar 2025) to address uneven ripening and enhance uniform colour development in four table grape varieties viz Red Globe, Crimson Seedless, Manjari Shyama and Sharad Seedless using plant bioregulators ABA (300 ppm), Ethylene (400 ppm) and control treatments in a Factorial Randomized Block Design. Results revealed significant varietal differences, with Manjari Shyama showing early ripening and superior anthocyanin content, while Red Globe recorded maximum berry size and yield. ABA @ 300 ppm improved yield, sugars content, anthocyanin concentration and shelf life, whereas Ethylene accelerated ripening and colour uniformity but reduced shelf life. Significant interaction effects indicated that treatment combinations, particularly Red Globe + ABA @ 300 ppm and Manjari Shyama + ABA @ 300 ppm, produced the best yield and quality traits. Overall, ABA and Ethylene effectively enhanced uniform ripening and colour development in table grapes.

Keywords: Colour, plant bioregulators, grapes, abscisic acid, ethephon

1. Introduction

Grapes (*Vitis vinifera* L.) are deciduous vines of great horticultural significance and rank among India's leading fruit crops. In 2023-24, as mentioned by Anon., (2023-24) ^[1] India had a total grape cultivation area of approximately 175.93 thousand hectares, accounting for 2.50 per cent of the total fruit-producing area. The country is also a prominent exporter of fresh grapes, with an export volume of 343,982.34 metric tons, valued at Rs. 3,595.06 crores.

Belonging to the Vitaceae family, grapes (*Vitis* sp.) hold commercial importance in India. Although primarily a temperate crop, it has adapted well to the sub-tropical climate of peninsular India. Maharashtra contributes nearly 80 per cent of the total grape production, followed by Karnataka and Tamil Nadu. Grapes contain about 20 per cent easily digestible sugars and are rich in essential minerals like calcium and phosphorus. Globally, grape production is largely dedicated to winemaking (82%), raisin production (10%) and fresh consumption (8%). However, in India, the majority of grapes are consumed fresh, with only a small portion processed into liquor and dried fruits such as raisins.

Plant bioregulators are synthetic compounds that influence plant growth and development when applied externally. These regulators play a crucial role in different growth stages, marking a significant advancement in horticultural research. In commercial grape production, they contribute to various aspects such as berry thinning, seedless berry formation, uniform colouration and overall fruit development.

Specific plant bioregulators, including abscisic acid (ABA), ethylene, pro-hexadione calcium and benzothiadiazole, have shown promising results in improving grape berry colour. Abscisic acid and ethylene are particularly vital for fruit development and ripening, serving as key hormones that initiate these processes. Ethylene, a gaseous compound plays a multifunctional role in plant life cycles, influencing germination, flowering, ripening, abscission and senescence. Various grape varieties, including Crimson Seedless, Kyoho, Cabernet Sauvignon and Merlot respond positively to ethylene and ABA applications, resulting in enhanced colouration and uniform ripening. Besides improving berry colour, these plant bioregulators also contribute to better berry size, total soluble solids, phenolic and

flavonoid content, ascorbic acid levels and antioxidant activity. Thus, their incorporation in viticulture can not only enhance market value but also increase the presence of bioactive compounds in grape berries.

Uneven ripening is a serious issue for colour grape cultivars, particularly under semi-arid subtropical conditions. Anthocyanins are the primary pigments responsible for berry colouration. Several factors, including physiological, chemical and environmental influence such as light exposure, temperature variations and plant hormone levels affect colour development in grape berries. Many red and black grape varieties fail to achieve the desired pigmentation due to non-ideal conditions related to light, temperature, soil moisture and nutrition. Among these, temperature plays a dominant role in uneven ripening under semi-arid subtropical conditions in India.

Efforts to address this problem include cultural practices like girdling, ringing and thinning, along with the application of plant bioregulators. These methods have shown promising results in enhancing grape quality. However, berry ripening often remains uneven within clusters, leading to unattractive, variably coloured and poor-quality berries in Indian viticulture. Ethylene, a gaseous plant hormone, is commercially available in the form of an aqueous solution called Ethrel (Ethephon 39 SL, 39% w/w). When sprayed on grape berries, Ethrel penetrates the skin and is transported within the berry and gradually breaks down to release ethylene, which enhances berry ripening and colouration. Recent studies suggest that applying bioregulators like abscisic acid and ethylene at the veraison stage (when berries begin ripening) can significantly improve colour development in Beauty Seedless and Flame Seedless varieties under semi-arid subtropical conditions. Thus, this experiment aims to investigate the following objective of studying the effect of plant bioregulators on colour enhancement and uneven ripening of different colour table varieties.

2. Materials and Methods

The research was conducted at the All India Co-ordinated Research Project on Fruits, Department of Horticulture, MPKV, Rahuri, from October 2024 to March 2025, with the objective of addressing uneven ripening and promoting uniform colour development in grapes. The experiment was carried out on healthy, vigorous, nine year old vines of four colour table grape varieties viz. Red Globe, Crimson Seedless, Manjari Shyama and Sharad Seedless planted at a spacing of 2.74 m × 1.52 m. The orchard was pruned on 15 October 2024. The study comprised twelve treatment combinations arranged in a Factorial Randomized Block Design with three replications, using two vines per treatment. The treatments involved spraying the vines with two plant bioregulators, ABA at 300 ppm and ethylene at 400 ppm, along with a control (water) with first spray at veraison stage and second spray at 8 days after first spray subsequently. The morphological traits days taken to veraison, days taken to achieve uniform colour and days taken to harvest were recorded while berry diameter was recorded with the help of vernier caliper, the yield traits like average berry weight (g), weight of 100 berries (g), number of bunches per vine, average bunch weight (g) and yield per vine (kg) were recorded at harvest. The data on quality attributes was recorded at harvest for TSS ($^{\circ}$ brix) using digital refractometer and for acidity (%), anthocyanin (%),

total sugars (%), reducing sugars (%) and non-reducing sugar (%) with all standard procedures for chemical analysis and for physiological loss in weight (%) and shelf life (days) the fruits were stored at room temperature after harvest. The data collected was subjected to statistical analysis following the method described by Panse and Sukhatme (1985) ^[28].

Table 1: Details of treatment combinations

Sr No.	Treatment Combinations	
1	V ₁ B ₁	Red Globe + Absciscic acid @ 300 ppm
2	V ₁ B ₂	Red Globe + Ethylene @ 400 ppm
3	V ₁ B ₃	Red Globe + Control (Water)
4	V ₂ B ₁	Crimson Seedless + Absciscic acid @ 300 ppm
5	V ₂ B ₂	Crimson Seedless + Ethylene @ 400 ppm
6	V ₂ B ₃	Crimson Seedless + Control (Water)
7	V ₃ B ₁	Manjari Shyama + Absciscic acid @ 300 ppm
8	V ₃ B ₂	Manjari Shyama + Ethylene @ 400 ppm
9	V ₃ B ₃	Manjari Shyama + Control (Water)
10	V ₄ B ₁	Sharad Seedless + Absciscic acid @ 300 ppm
11	V ₄ B ₂	Sharad Seedless + Ethylene @ 400 ppm
12	V ₄ B ₃	Sharad Seedless + Control (Water)

3. Results and Discussion

3.1 Growth parameters

Significant effects of colour table varieties and plant bioregulators on morphological traits were recorded and are presented in Table 2.

3.1.1 Days taken to veraison

Among the four varieties tested, cv. Manjari Shyama recorded the significantly lesser days to veraison (84.33 days), followed by cv. Sharad Seedless (86.22 days). The varieties Red Globe (97.50 days) took more number of days to reach veraison. The effect of plant bioregulators was non significant as the spray was scheduled at veraison stage and 8 days after veraison subsequently but, numerically mean days taken to veraison across treatments were ABA @ 300 ppm (90.25 days), Ethylene @ 400 ppm (89.71 days) and Control (89.96 days). The significantly less number of days taken to veraison was recorded in interaction V₃B₂ (Manjari Shyama + Ethylene @ 400 ppm) and interaction V₃B₃ (Manjari Shyama + Control) (each 84.17 days), followed by interaction V₃B₁ (Manjari Shyama + ABA @ 300 ppm) (84.67 days). The maximum number of days (97.67 days) to veraison was recorded by the interaction V₁B₁ (Red Globe with ABA @ 300 ppm). The varietal traits significantly impact the timing of veraison in grapes and plant bioregulators accelerates post-veraison processes like anthocyanin synthesis and sugar accumulation, rather than triggering the start of veraison as reported by Chervin *et al.*, (2005) ^[6], Koyama *et al.*, (2010) ^[19] and Ferrara *et al.*, (2013) ^[10].

3.1.2 Days to achieve uniform colour

Cultivar Manjari Shyama recorded significantly minimum days (94.67 days) to achieve uniform colour. In contrast, cv. Red Globe took significantly more number of days (110.67) to attain uniform berry colouration. The effect of plant bioregulators ABA @ 300 ppm (101.50 days) and Ethylene @ 400 ppm (100.83 days) were at par to each other and significantly reduced the time to achieve uniform colour development compared to the control (105.50 days). Among the interactions, interaction V₃B₂ (Manjari Shyama + Ethylene @ 400 ppm) took significantly minimum days to

achieve uniform colour (92.50 days), followed by interaction V_3B_1 (Manjari Shyama + ABA @ 300 ppm) (94.33 days). While the maximum days was recorded in interaction V_1B_3 (Red Globe + Control) (115.00 days). ABA is known to regulate the expression of anthocyanin related genes such as UFGT, CHS and DFR, which enhances berry pigmentation reported by Jeong *et al.*, (2004) ^[15], Peppi *et al.*, (2008) ^[32] and Koyama *et al.*, (2010) ^[19]. Ethephon enhances internal ethylene production, which indirectly promotes ABA synthesis, thereby improving uniform colour development (Chakravar and Rane 1977) ^[5] and Chervin *et al.*, (2008) ^[7].

3.1.3 Days taken to harvest

Among the tested grape cultivars, Manjari Shyama and Sharad Seedless exhibited earlier maturity, recording 120.00 days and 121.50 days respectively and were statistically at par with each other, whereas Red Globe required the longer duration (140.00 days), followed by Crimson Seedless (137.00 days). The significantly shortest mean duration to harvest was recorded in vines treated with Ethylene @ 400 ppm (126.00 days) from pruning, while the control (water) took longer duration to harvest (134.54 days). The earlier harvest (116.17 days) from pruning was recorded in interaction V_3B_2 (Manjari Shyama + Ethylene @ 400 ppm), at par with V_4B_2 (Sharad Seedless + Ethylene @ 400 ppm) (117.67 days) and V_3B_1 (Manjari Shyama + ABA @ 300 ppm) (118.67 days). In contrast, interaction V_1B_3 (Red Globe + control) required maximum days (144.83) to harvest. These findings are in accordance with Ferrara *et al.*, (2013) ^[10], who reported that ABA and Ethephon treatments at veraison led to earlier harvest in Crimson Seedless.

3.1.4 Berry diameter (mm)

According to the data, larger berries were recorded in Red Globe (23.14 mm), followed by Manjari Shyama (22.15 mm) and Crimson Seedless (21.41 mm), while the smaller berries were observed in Sharad Seedless (19.60 mm). Application of ABA @ 300 ppm recorded significant higher mean value for berry diameter (21.90 mm) among the treatments statistically at par with Ethylene @ 400 ppm (21.64 mm), while the bunches treated with water recorded the smallest berry diameter (21.18 mm). Among all the interactions V_1B_1 (Red Globe + ABA @ 300 ppm) recorded significant larger berry diameter (23.38 mm) at par with V_1B_2 (Red Globe + Ethylene @ 400 ppm) (23.12 mm) and V_1B_3 (Red Globe + Water) (22.93 mm). Whereas, the smaller berry diameter (19.47 mm) measured in V_4B_3 (Sharad Seedless + Water). These results are supported by findings by Pilati *et al.*, (2007) ^[33], Parseh *et al.*, (2009) ^[29] and Koyama *et al.*, (2010) ^[19] who reported that ABA influences the expression of aquaporins and expansions, which are directly involved in cell wall loosening and water movement—two processes essential for berry enlargement and Ethylene also modifies berry texture and softening enzymes like pectin methylesterase and polygalacturonase, leading to moderate changes in volume of berry.

3.2. Yield parameters

Significant effects of colour table varieties and plant bioregulators on yield traits were recorded and are presented in Table 2.

3.2.1 Average weight of berry (g): Among the varieties,

Red Globe recorded significantly highest average weight of berry of 5.40 g, followed by Manjari Shyama (3.37 g) and then Crimson Seedless (2.95 g), while the lowest weight was observed in Sharad Seedless (2.33 g). Among the treatments, ABA @ 300 ppm showed the maximum mean berry weight (3.65 g) at par with Ethylene @ 400 ppm (3.57 g), whereas the control recorded the lowest value (3.31 g). The interaction V_1B_1 (Red Globe + ABA @ 300 ppm) recorded significantly higher berry weight of (5.49 g) at par with interaction V_1B_2 (Red Globe + Ethylene @ 400 ppm) (5.41 g) and V_1B_3 (Red Globe + Control) (5.29 g). Ethylene softens berry tissues and alters cell wall metabolism, which might have led to increase in berry mass according to Parseh *et al.*, (2009) ^[29], Baghdady *et al.*, (2020) ^[2] and Ibrahim *et al.*, (2022) ^[14]. While these results corroborate with Mhetre. *et al.*, (2021) ^[24], who reported that ABA-treated vines of table grapes like Beauty Seedless and Flame Seedless had slight heavier berries compared to untreated vines.

3.2.2 Weight of 100 berries (g)

Among the four grape varieties, cv. Red Globe recorded the significantly more weight for 100 berries (567.44 g), followed by cv. Manjari Shyama (344.56 g), while Crimson Seedless (287.06 g) recorded the lowest weight for 100 berries. The significantly maximum weight of 100 berries was recorded under ABA @ 300 ppm (380.92 g), followed by Ethylene @ 400 ppm (373.21 g). However, the lowest 100 berry weight (360.67 g) was recorded in the control treatment. Among all the treatment combinations, the significantly maximum weight of 100 berries was observed in interaction V_1B_1 (Red Globe + ABA @ 300 ppm) (586.00 g), followed closely by interaction V_1B_2 (Red Globe + @ 400 ppm) (578.33 g). and significantly lowest weight (281.83 g) in interaction V_4B_3 (Sharad Seedless + Control). ABA improves the function of aquaporins, which regulate water transport into the berry tissues, further contributing to increased fresh weight as reported by Deng *et al.*, (2019) ^[8] and Bennett *et al.*, (2023) ^[3]. While Ethylene assists in improving berry softening and may indirectly influence water retention and berry swelling (Weaver and Pool 1971) ^[42], Koyama *et al.* (2010) ^[19] and Ibrahim *et al.* (2022) ^[14].

3.2.3 Number of bunches per vine

For the data on number of bunches per vine in table 2, cv. Crimson Seedless recorded the highest significant number of bunches (25.94) per vine at par with cv. Manjari Shyama (24.33), followed by cv. Sharad Seedless recording 23.17 bunches per vine. The comparatively lower number of bunches was noted in cv. Red Globe (11.83). The effect of plant bioregulators for number of bunches per vine was found non-significant as the bunch formation takes place before veraison at which the spray of plant bioregulators was scheduled. Among the interactions, The highest number of bunches per vine (26.50) was recorded in interaction V_2B_3 (Crimson Seedless+ Control), at par with all the other interactions among Crimson Seedless, Manjari Shyama and Sharad Seedless with plant bioregulators and the lowest number of bunches (11.17) was reported in interaction V_1B_2 (Red Globe + Ethylene @ 400 ppm). The findings are aligned with reports by Peppi *et al.*, (2006) ^[31], Roberto *et al.*, (2012) ^[35], and Kumar *et al.*, (2017) ^[21] who emphasized that fruit number per vine is more related to cultural practices and varietal response than to hormonal

applications alone.

3.2.4 Average bunch weight (g)

Significant variation was reported from data in table 2 on average bunch weight among the grape varieties studied. Red Globe recorded the highest average bunch weight (683.96 g), followed by Manjari Shyama (304.22 g), Sharad Seedless (228.72 g) and the lowest in Crimson Seedless (205.94 g). Among the treatments, application of ABA @ 300 ppm resulted in the highest average bunch weight (363.81 g), at par with Ethylene @ 400 ppm, (359.58 g) and the control recorded comparatively lowest value (343.74 g). Among all the interactions, the Red Globe variety treated with ABA @ 300 ppm (V_1B_1) recorded the higher average bunch weight (700.13 g), at par with interaction V_1B_2 (Red Globe + Ethylene @ 400 ppm) (683.03 g) showing a substantial increase over the interaction V_1B_3 (Red Globe + Control) (668.70 g). ABA and Ethylene have indirectly improved berry development and bunch weight by enhancing sink strength and sugar accumulation post-veraison, as suggested by Parseh *et al.*, (2009) ^[29], Baghdady *et al.*, (2020) ^[2] and Mhetre *et al.*, (2021) ^[24].

3.2.5 Yield per vine (kg)

According to data in table 2, cv. Red Globe recorded highest significant yield (8.32 kg) per vine at par with Manjari Shyama (7.59 kg) per vine, while the lowest yield was recorded in Sharad Seedless (5.31 kg) per vine. ABA @ 300 ppm recorded the higher mean value for yield (7.09 kg) per vine at par with Ethylene @ 400 ppm recording (6.65 kg) per vine showing superiority over the vines treated with water (6.26 kg). The highest yield (8.87 kg) per vine was recorded in interaction V_1B_1 (Red Globe + ABA @ 300 ppm) at par with interaction V_1B_2 (Red Globe + Ethylene @ 400 ppm) (8.29 kg) per vine, interaction V_3B_1 (Manjari Shyama + ABA @ 300 ppm) (7.90 kg) per vine, interaction V_1B_3 (Red Globe + Control) (7.82 kg) per vine, interaction V_3B_2 (Manjari Shyama + Ethylene @ 400 ppm) (7.57 kg) per vine and interaction V_3B_3 (Manjari Shyama + Control) (7.28 kg) per vine. The lowest yield (4.80 kg) per vine was recorded in interaction V_4B_3 (Sharad Seedless + Control). These observations are supported by Gouda *et al.*, (2019) ^[12] who highlighted that the effect of ABA on yield and berry growth in Red Roomy grapes was more pronounced compared to other cultivars,

3.3. Quality Parameters

3.3.1. TSS ($^{\circ}$ Brix)

The data in table 3 reveals that, Cultivar Manjari Shyama recorded the highest significant mean TSS (17.71 $^{\circ}$ Brix) and at par to cv. Sharad Seedless (17.63 $^{\circ}$ Brix) followed by cv. Crimson Seedless (17.17 $^{\circ}$ Brix) and the lowest in cv. Red Globe (16.06 $^{\circ}$ Brix). Among the treatments, application of Absciscic Acid (ABA @ 300 ppm) resulted in the higher average TSS (17.40 $^{\circ}$ Brix), which is at par with Ethylene @ 400 ppm (17.19 $^{\circ}$ Brix) and the control (water) recorded the significantly lowest TSS (16.83 $^{\circ}$ Brix). Among the interactions, V_3B_1 (Manjari Shyama + ABA @ 300 ppm) recorded (18.1 $^{\circ}$ Brix) which was significantly higher value and at par with interaction V_4B_1 (Sharad Seedless + ABA @ 300 ppm) (17.9 $^{\circ}$ Brix), interaction V_3B_2 (Manjari Shyama + Ethylene @ 400 ppm) (17.8 $^{\circ}$ Brix) and interaction V_4B_1 (Sharad Seedless + Ethylene @ 400 ppm) (17.6 $^{\circ}$ Brix). Whereas, lowest value for TSS (15.9 $^{\circ}$ Brix) was recorded in

berries of cv. Red Globe treated with water spray, i.e., interaction (V_3B_3). These findings align with Ferrara *et al.*, (2015) ^[11] and Murcia *et al.*, (2016) ^[26] who noted similar enhancements in TSS in Crimson Seedless grapes. Similarly, Szyjewicz *et al.*, (1984) ^[41] and Chervin *et al.*, (2005) ^[6] observed a notable increase in sugar content in ethephon-treated grape berries due to faster maturation and higher respiration rates during the late stages of ripening.

3.3.2 Acidity (%)

From the data in table 3, among all varieties, Manjari Shyama reported significantly minimum acidity (0.59%), at par with Crimson Seedless recorded (0.60%), while Red Globe recorded the highest acidity (0.64%). Ethylene application at concentration of 400 ppm led to the lowest acidity (0.59%), at par with ABA @ 300 ppm treatment (0.61%), whereas the untreated berries exhibited the highest acidity (0.65%). The significant minimum values for titratable acidity (%) was recorded in both the interactions V_2B_2 (0.57%) and V_3B_2 (0.57%) where both varieties Crimson Seedless and Manjari Shyama were sprayed with 400 ppm concentration solution of ethylene, at par with interactions V_2B_1 (0.59%) and V_3B_1 (0.59%) where both varieties Crimson Seedless and Manjari Shyama were sprayed with 300 ppm concentration solution of ABA and interaction V_4B_2 (0.58%) where Sharad Seedless was sprayed with Ethylene @ 400 ppm concentration. While the highest value (0.67%) was recorded in interaction V_1B_3 (Red Globe sprayed with water). These findings align with Parseh *et al.*, (2009) ^[29] and Kumar *et al.*, (2017) ^[21], who reported that ethylene and ABA treatments significantly reduced acidity in Beidaneh Ghermez grapes, especially when applied at veraison.

3.3.3 TSS: Acid ratio

The data on TSS: Acid ratio in table 3 reveals that, Among the varieties, Manjari Shyama recorded the significant highest TSS: acid ratio (29.97), followed by Sharad Seedless (28.81) and lowest in Red Globe (25.18). Among the bioregulator treatments, Ethylene @ 400 ppm recorded the highest mean TSS:acid ratio (29.59), followed by ABA @ 300 ppm (28.69) and the lowest in control (26.23). The highest TSS:acid ratio was recorded in interaction V_3B_2 (Manjari Shyama + Ethylene @ 400 ppm) (31.32) at par with interaction V_3B_1 (Manjari Shyama + ABA @ 300 ppm) (30.59), interaction V_2B_2 (Crimson Seedless + Ethylene @ 400 ppm) (30.35) and interaction V_4B_2 (Sharad Seedless + Ethylene @ 400 ppm) (30.17), while the lowest was recorded in Red Globe + control (23.79). These results align with Cantin *et al.*, (2007) ^[4], Peppi *et al.*, (2007) ^[30] and Parseh *et al.*, (2009) ^[29] who reported that ABA and Ethephon application at veraison stage improved the sugar-to-acid balance by enhancing sugar transport and reducing acid synthesis and enhance sweetness perception and better quality indices.

3.3.4 Anthocyanin (mg/100g)

Among the four varieties, cv. Manjari Shyama (31.36 mg/100g) recorded the significant higher anthocyanin content at par with cv. Sharad Seedless (30.56 mg/100g) followed by cv. Crimson Seedless (28.39 mg/100g) and significantly lower in Red Globe (25.50 mg/100g). Among the treatments, ABA @ 300 ppm recorded the significantly highest mean anthocyanin content (32.58 mg/100g),

followed by Ethylene @ 400 ppm (29.14 mg/100g), while the control (water spray) resulted in the significantly lower value (25.13 mg/100g). The significant higher anthocyanin content was observed in interaction V₃B₁ Manjari Shyama + ABA @ 300 ppm (35.56 mg/100g), followed by interaction V₄B₁ (Sharad Seedless + ABA @ 300 ppm) (33.83 mg/100g) and interaction V₂B₁ (Crimson Seedless + ABA @ 300 ppm) (31.89 mg/100g). In contrast, the significantly lowest anthocyanin values were recorded in interaction V₁B₃ (Red Globe + Control) (21.89 mg/100g) as per the data recorded in table 3. ABA stimulated rapid activation of genes involved in anthocyanin biosynthesis such as VvMYBA1, UFGT, and DFR, which led not only to elevated pigment levels as reported by Jeong *et al.*, (2004) ^[15], Koyama *et al.*, (2010) ^[19] and Ferrara *et al.*, (2013) ^[10]. Also according to Chervin *et al.*, (2005) ^[6] and Sun *et al.*, (2010) ^[40] ethephon-induced ethylene may stimulate ABA biosynthesis, leading to synergistic effects that partially mimic ABA's direct influence and can improve ripening uniformity by promoting chlorophyll degradation, stimulating carotenoid and flavonoid biosynthesis.

3.3.5. Total sugars (%)

From the data recorded in table 3 Among the varieties, cv. Sharad Seedless recorded the significantly highest mean total sugar content (17.01%), followed by cv. Manjari Shyama (16.40%), while cv. Red Globe had the significantly lowest total sugars (15.16%). Spraying ABA at 300 ppm to the varieties resulted in the significantly highest total sugar content (16.22%), at par with Ethylene at 400 ppm (16.04%) while significantly lower value in control (15.84%). The significantly highest total sugar percentage was observed in interaction V₄B₁ (Sharad Seedless + ABA @ 300 ppm) (17.17%), at par to interactions V₄B₂ (Sharad Seedless + Ethylene @ 400 ppm) (17.01%) and V₄B₃ (Sharad Seedless sprayed with water) (16.84%), while the significant lowest sugar content was recorded for interaction V₁B₃ (Red Globe + control) (14.87%). The slight increase in total sugars (%) align with the results revealed by Peppi *et al.*, (2006) ^[31] and Ferrara *et al.*, (2015) ^[11] where ABA and ethylene lead to slight effect on sugar accumulation within the berries.

3.3.6. Reducing sugars (%)

The data in table 3 revealed that, cv. Sharad Seedless recorded the highest significant mean value (15.30%), at par with cv. Manjari Shyama (14.68%), while cv. Red Globe (13.60%) exhibited lower reducing sugar values among all the varieties under treatment. Among the plant bioregulators, ABA @ 300 ppm significantly showed slight increase in mean reducing sugar content (14.70%) at par with Ethylene @ 400 ppm (14.34%) and control (13.90%) treated vines. The highest reducing sugar content (15.73%) was observed in interaction V₄B₁ (Sharad Seedless + ABA @ 300 ppm) at par with interactions V₄B₂ (Sharad Seedless + Ethylene @ 400 ppm) (15.35%), V₃B₁ (Manjari Shyama + ABA @ 300 ppm) (14.95%), V₄B₃ (Sharad Seedless + Water spray) (14.83%), V₃B₂ (Manjari Shyama + Ethylene @ 400 ppm) (14.57%) and V₃B₃ (Manjari Shyama + control) (14.51%), The lowest value was recorded in interaction V₁B₃ (Red Globe + Control) (13.01%). Ethylene modulate sugar accumulation indirectly by enhancing respiration and promoting membrane permeability, as discussed by Parseh *et al.*, (2009) ^[29]. Also, Huang *et al.*,

(2025) ^[13] reported that ABA modulates expression of SnRK1 and invertase genes, which enhances sucrose breakdown into reducing sugars like glucose and fructose, especially during the veraison and post-veraison phase.

3.3.7. Non-reducing Sugars

The data in table 3 clearly reports the effect of varieties and plant bioregulators and interactions among them were found non-significant but numerically the non-reducing sugars were found highest in Crimson Seedless (1.82%) and lowest in Red Globe (1.48%) among the varieties, while among plant bioregulators Control has reported highest mean non reducing sugar content (1.85%) and lowest in vines treated with ABA @ 300 ppm (1.45%). Among the interactions, highest non-reducing sugar content was found in interaction V₂B₃ (Crimson Seedless + Control) (2.00%) and lowest in interaction V₁B₁ (Red Globe + ABA @ 300 ppm) (1.17%). Kuhn *et al.*, (2013) ^[20] reported that grapevine cultivars respond differently to exogenous hormone applications due to differences in their hormonal sensitivity and metabolic activity and also these findings are consistent with the work of Peppi *et al.*, (2006) ^[31] and Kumar *et al.*, (2020) ^[22].

3.3.8 PLW (%)

The data in table 4 revealed that At 5 DAS among the varieties, cv. Crimson Seedless showed significantly lower weight loss (6.70%) statistically at par with cv. Red Globe (6.92%), while cv. Sharad Seedless recorded significantly higher weight loss (8.40%). From plant bioregulators at 5 DAS, the significantly lowest PLW was recorded with ABA @ 300 ppm (7.00%), statistically at par with control (7.28%), while Ethylene @ 400 ppm (7.72%) resulted in the highest weight loss. The significant lower PLW (%) 5 DAS (Days After Storage) was observed in interaction V₂B₁ (Crimson Seedless + ABA @ 300 ppm) (6.43%) at par with interactions V₁B₁ (Red Globe + ABA @ 300 ppm) (6.65%), V₂B₃ (Crimson Seedless +Control) (6.68%), V₁B₃ (Red Globe + Control) (6.81%), V₃B₁ (Manjari Shyama + ABA @ 300 ppm) (6.92%) and V₂B₂ (Crimson Seedless + Ethylene @ 400 ppm) (7.01%) at 5 DAS. While the higher weight loss was (8.78%) recorded in interaction V₄B₂ (Sharad Seedless + Ethylene @ 400 ppm). These results align with the findings, where Cantin *et al.*, (2007) ^[4], Ferrara *et al.*, (2015) ^[11] and Khillari *et al.*, (2019) ^[17] found that exogenous ABA enhances shelf life by reducing weight loss, decay incidence and delaying senescence, particularly in table grapes. While ethylene accelerates senescence, increasing membrane permeability and cuticular degradation, thereby enhancing water loss was confirmed by Chervin *et al.*, (2005) ^[6] and Sun *et al.*, (2010) ^[40].

3.3.9. Shelf life (days)

Among the varieties with cv. Crimson Seedless (4.76 days) showing significantly higher value and at par with cultivars Red Globe (4.69 days) and Manjari Shyama (4.52 days), while cv. Sharad Seedless recorded lower shelf life (4.39 days) under ambient conditions. Application of ABA @ 300 ppm significantly extended mean shelf life (5.43 days), compared to control (4.65 days) and ethylene @ 400 ppm (3.68 days). The longer shelf life was observed in interaction V₂B₁ (Crimson Seedless + ABA @ 300 ppm) (5.72 days) at par with interactions V₁B₁ (Red Globe + ABA @ 300 ppm) (5.50 days) and V₃B₁ (Manjari Shyama + ABA @ 300 ppm) (5.28 days), while the shortest shelf life was in

interaction V₄B₂ (Sharad Seedless + Ethylene @ 400 ppm) (3.50 days). The results obtained here in this experiment

recorded in table 4 align with the findings of Khillari *et al.*, (2019)^[17] and Mohamed *et al.*, (2023)^[25].

Table 2: Effect of colour table varieties and plant bioregulators on morphological and yield attributes

Treatment Details	Days to Veraison	Days to achieve uniform color	Days to Harvest	Berry Diameter (mm)	Berry Weight (g)	Weight of 100 Berries (g)	Number of bunches/vine	Average bunch weight (g)	Yield/ wine (kg)
A. Varieties									
V1 (Red globe)	97.50	110.67	140.00	23.14	5.40	567.44	11.83	683.96	8.32
V2 (Crimson Seedless)	91.83	108.33	137.00	21.41	2.95	287.06	25.94	205.94	5.46
V3 (Manjari Shyama)	84.33	94.67	120.00	22.15	3.37	344.56	24.33	304.22	7.59
V4 (Sharad Seedless)	86.22	96.78	121.50	19.60	2.33	287.33	23.17	228.72	5.31
SEm±	0.47	0.35	0.52	0.11	0.04	2.43	0.94	5.61	0.32
CD at 5%	1.39	1.04	1.52	0.33	0.12	7.12	2.74	16.46	0.95
B. Plant Bioregulators									
B1 (ABA 300 ppm)	90.25	101.50	128.33	21.90	3.65	380.92	22.08	363.81	7.09
B2 (Ethylene 400 ppm)	89.71	100.83	126.00	21.64	3.57	373.21	21.00	359.58	6.65
B3 (Water spray)	89.96	105.50	134.54	21.18	3.31	360.67	20.88	343.74	6.26
SEm±	0.30	0.31	0.45	0.10	0.03	2.10	0.81	4.86	0.28
CD at 5%	NS	0.90	1.32	0.28	0.10	6.16	NS	14.25	0.81
Interaction (Variety x Plant Bioregulator Concentration)									
(V1 B1)	97.67	109.33	139.17	23.38	5.49	586.00	12.67	700.13	8.87
(V1 B2)	97.50	107.67	136.00	23.12	5.41	578.33	11.17	683.03	8.31
(V1 B3)	97.33	115.00	144.83	22.93	5.29	538.00	11.67	668.70	7.80
(V2 B1)	91.83	106.00	135.50	21.85	3.11	291.67	26.00	206.33	5.80
(V2 B2)	91.33	107.33	134.17	21.61	3.05	285.33	25.33	215.67	5.41
(V2 B3)	92.33	111.67	141.33	20.75	2.69	284.17	26.50	195.83	5.16
(V3 B1)	84.67	94.33	118.67	22.54	3.53	352.00	25.33	311.13	7.89
(V3 B2)	84.17	92.50	116.17	22.36	3.42	343.00	24.83	304.00	7.55
(V3 B3)	84.17	97.17	125.17	21.56	3.15	338.67	22.83	297.33	7.28
(V4 B1)	86.83	96.33	120.00	19.85	2.49	294.00	24.33	237.43	5.78
(V4 B2)	85.93	95.83	117.67	19.48	2.40	286.17	22.67	235.63	5.34
(V4 B3)	86.00	98.17	126.83	19.47	2.10	281.83	22.50	213.08	4.79
SEm±	0.60	0.61	0.90	0.19	0.07	4.20	1.63	9.72	0.58
CD at 5%	1.75	1.80	2.64	0.57	0.22	12.32	4.77	28.72	1.71

Table 3: Effect of colour table varieties and plant bioregulators on quality attributes

Treatment Details	TSS (°Brix)	Titration acidity (%)	TSS:Acid	Anthocyanin (mg/100g)	Total Sugars (%)	Reducing Sugars (%)	Non-reducing Sugar (%)
A. Varieties							
V1 (Red globe)	16.06	0.64	25.18	25.50	15.16	13.60	1.48
V2 (Crimson Seedless)	17.17	0.60	28.72	28.39	15.57	13.65	1.82
V3 (Manjari Shyama)	17.71	0.59	29.97	31.36	16.40	14.68	1.64
V4 (Sharad Seedless)	17.63	0.62	28.81	30.56	17.01	15.30	1.62
SEm±	0.10	0.01	0.34	0.28	0.08	0.28	0.25
CD at 5%	0.31	0.02	0.99	0.83	0.25	0.83	NS
B. Plant Bioregulators							
B1 (ABA 300 ppm)	17.40	0.61	28.69	32.58	16.22	14.70	1.45
B2 (Ethylene 400 ppm)	17.19	0.59	29.59	29.14	16.04	14.34	1.61
B3 (Water spray)	16.83	0.65	26.23	25.13	15.84	13.90	1.85
SEm±	0.09	0.01	0.29	0.25	0.07	0.25	0.21
CD at 5%	0.27	0.02	0.86	0.72	0.21	0.72	NS
Interaction (Variety x Plant Bioregulator Concentration)							
(V1 B1)	16.2	0.64	25.51	29.06	15.46	14.23	1.17
(V1 B2)	16.1	0.61	26.25	25.54	15.15	13.57	1.49
(V1 B3)	15.9	0.67	23.79	21.89	14.87	13.01	1.77
(V2 B1)	17.4	0.59	29.58	31.89	15.76	13.87	1.79
(V2 B2)	17.2	0.57	30.35	29.63	15.60	13.85	1.65
(V2 B3)	16.9	0.65	26.2	23.65	15.35	13.24	2.00

(V3 B1)	18.1	0.59	30.59	35.83	16.51	14.95	1.48
(V3 B2)	17.8	0.57	31.32	30.88	16.40	14.57	1.73
(V3 B3)	17.2	0.62	27.89	27.64	16.31	14.51	1.71
(V4 B1)	17.9	0.62	29.03	33.83	17.17	15.73	1.37
(V4 B2)	17.6	0.58	30.17	30.49	17.01	15.35	1.57
(V4 B3)	17.4	0.64	27.12	27.36	16.84	14.83	1.91
SEm±	0.18	0.01	0.58	0.49	0.15	0.49	0.43
CD at 5%	0.53	0.03	1.72	1.45	0.43	1.44	NS

Table 4: Effect of colour table varieties and plant bioregulators on physiological loss in weight (%) and shelf life

Treatment Details	PLW (%)			Shelf life (days)
	1 DAS	3 DAS	5 DAS	
A. Varieties				
V1 (Red globe)	1.27	3.57	6.92	4.69
V2 (Crimson Seedless)	1.20	3.43	6.70	4.76
V3 (Manjari Shyama)	1.24	4.06	7.34	4.52
V4 (Sharad Seedless)	1.51	4.21	8.40	4.39
SEm±	0.05	0.13	0.12	0.09
CD at 5%	0.14	0.37	0.34	0.26
B. Plant Bioregulators				
B1 (ABA 300 ppm)	1.16	3.51	7.00	5.43
B2 (Ethylene 400 ppm)	1.49	3.83	7.72	3.68
B3 (Water spray)	1.27	3.78	7.28	4.65
SEm±	0.04	0.11	0.10	0.18
CD at 5%	0.12	0.30	0.30	0.23
Interaction (Variety x Plant Bioregulator Concentration)				
(V1 B1)	1.13	3.33	6.65	5.50
(V1 B2)	1.47	4.03	7.30	3.78
(V1 B3)	1.22	3.36	6.81	4.78
(V2 B1)	1.07	3.12	6.43	5.72
(V2 B2)	1.36	3.72	7.01	3.72
(V2 B3)	1.16	3.44	6.68	4.83
(V3 B1)	1.14	3.77	6.92	5.28
(V3 B2)	1.40	4.39	7.81	3.72
(V3 B3)	1.18	4.01	7.30	4.56
(V4 B1)	1.33	3.82	8.06	5.22
(V4 B2)	1.67	4.51	8.78	3.50
(V4 B3)	1.53	4.30	8.36	4.44
SEm±	0.09	0.22	0.20	0.15
CD at 5%	0.27	0.64	0.59	0.45

4. Conclusion

The study demonstrated that preharvest application of ABA and Ethylene at veraison and 8 days after veraison positively influenced ripening, colour development, and berry quality in all four table grape varieties. For growth parameters, cv. Manjari Shyama has taken significantly minimum days to veraison, days to achieve uniform colour and days to harvest and for berry diameter cv. Red Globe was found superior. From plant bioregulators Ethylene was effective in fastening uniform colour development and early harvest while berry diameter was increased by ABA. The interaction V₃B₂ (Manjari Shyama + Ethylene @ 400 ppm) has recorded significant results by achieving uniform colour in fruits and harvesting earlier than those treated with control but, berry diameter was found superior in interaction V₁B₁ i.e., Red Globe + ABA @ 300 ppm. For yield parameters, cv. Red Globe was found superior for average weight of berry, 100 berry weight, average bunch weight and yield per vine among the varieties. In case of PBR, ABA @ 300 ppm has significantly increased average weight of berry, 100 berry weight, average bunch weight and yield per vine. Therefore, the interaction V₁B₁ i.e., Red Globe + ABA @ 300 ppm was found best with superior results for all the yield parameters. In case of quality parameters, cv. Manjari Shyama was found superior with higher TSS, TSS:acid ratio, anthocyanin

and lower acidity, cv. Sharad Seedless for higher total sugars and reducing sugars and cv. Crimson Seedless for minimum PLW% and longer shelf life. Among the PBRs, ABA @ 300 ppm has effectively increased TSS, anthocyanin, total sugars, reducing sugars and shelf life, while decreasing the PLW%. The interaction V₃B₁ (Manjari Shyama + ABA @ 300 ppm) for higher TSS and Anthocyanin, V₃B₂ (Manjari Shyama + Ethylene @ 400 ppm) for lower acidity and higher TSS: acid ratio, V₄B₁ (Sharad Seedless + ABA @ 300 ppm) for higher Total sugars and reducing sugars, while interaction V₂B₁ (Crimson Seedless + ABA @ 300 ppm) for lower PLW% and longer shelf were found best among all the interactions.

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