Study of Effects of Plant Growth Regulators on Fruit Quality of Table Grape

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Abstract The effects of different treatments on the seedlessness and fruit quality of 'Miguang' table grape was studied by using plant growth regulators, gibberellin acid (GA_3) and forchlorfenuron (CPPU), under different concentrations and application time. The results showed that the effects of different treatments on the seedlessness and fruit quality were different. Seedless rate, cluster weight, berry weight, berry shape index, soluble solid content, total acid content, soluble solids to acidity ratio, pulling resistance, turgor pressure and flesh firmness without skin were comprehensively evaluated, as a result of which, the optimum treatment on 'Miguang' table grape was to apply with GA_3 20 mg/L + SM 200 mg/L at one week before bloom and GA_3 25 mg/L + CPPU 3 mg/L at two weeks after bloom.

Key words Plant growth regulators; Seedlessness; Fruit quality

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As an important commercial crop in our country, grape has rich nutritional value, which is loved by the masses of consumers, and mainly focuses on table grape consumption[1]. With the continuous improvement of the economic level, consumers have higher requirements for the quality and taste of grapes, and seedless and large grapes have become the general trend of production and consumption of table grapes in China[2]. However, there are few seedless and early maturing table grape varieties in China, thus difficult to meet the demands of consumers[3]. Therefore, the seedlessness technology of table grapes has been paid attention to and widely used in production[4].

Gibberellin (GA_3), as one of the most widely used plant growth regulators in grape production, can promote the elongation of inflorescence used before flowering, inhibit the development of embryo sac and pollen and lead to seedless grape[5]; and when used at blooming stage, it can promote the fruit cell division, enlarge and lengthen the flesh cells, so as to enlarge the fruit. Chloropylurea (CPPU), as a plant growth regulator with cytokinin activity, can promote fruit setting and cell division, increase cell volume and promote fruit expansion[6-7]. Previous studies have shown that GA_3 played a key role in inducing grape seedlessness, while CPPU and SM played an auxiliary role[8]. On the one hand, the use of streptomycin (SM) can significantly improve the seedless rate in table grapes, and on the other hand, it can also reduce the hardening and peg of the stem, thereby reducing the side effects of GA_3. The addition of CPPU can significantly improve the seedless rate in table grapes[9-10]. The improper use of plant growth regulators can cause grape cluster loosening, stem hardening, berry dropping and so on, which seriously reduces commodity value[11-13]. Therefore, the scientific and reasonable use of plant growth regulators is of great significance to grape production.

'Miguang' is an early maturing table grape of rich Muscat flavor, and the use of plant growth regulators to produce seedless table grapes opens up a new way to enhance the value of its commodities. The effects of plant growth regulator concentration and application time on the quality and seedless rate of 'Miguang' grape were studied, aiming to provide a reference for the proper use of plant growth regulators in the cultivation of 'Miguang' grape.

Materials and Methods

Materials

The test was conducted at Shigezhuang Base of Changli Institute of Pomology, Hebei Academy of Agriculture and Forestry Sciences, located at 39°45′12″ N, 119°12′23″ E, with an altitude of 20 m and a subhumid continental monsoon climate. The soil was sandy loam.

'Miguang' table grape was planted in multi-span greenhouses in 2015. The trees were cultivated with one trunk shape, in north-south row, with spacing of 0.8 m × 4.5 m (plant × row), and under conventional management.

Tested agents: GA_3 (20%, Biolegend, San Diego, CA.), CPPU (trade name chlorfenuron, 0.1%, Sichuan Runer Technology Co., LTD.), SM (Hebei Yuanzheng Pharmaceutical Co., LTD.).

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Methods

The experiment was conducted in 2023. Plants with healthy and uniform growth were selected. The experiment set three replicates with five clusters in each replication. During the period of treatment, the cluster was dipped in the medicinal solution for 5 s with water as the control. The treatment methods are shown in Table 1.

Table 1 Design of tests in 'Miguang' table grape

Treatment	Treatment method
MCK	Control (water)
MT1	Two weeks before bloom GA_3 15 mg/L + SM 200 mg/L, 12d after bloom GA_3 25 mg/L + CPPU 3 mg/L
MT2	One week before bloom GA_3 20 mg/L + SM 200 mg/L, 12 d after bloom GA_3 25 mg/L + CPPU 3 mg/L
MT3	Late flowering stage GA_3 25 mg/L + SM 200 mg/L, 12 d after bloom GA_3 25mg/L + CPPU 3mg/L
MT4	Two weeks before bloom GA_3 10 mg/L, full bloom GA_3 25 mg/L + SM 200 mg/L + CPPU 3 mg/L, 12 d after bloom GA_3 25 mg/L + CPPU 3 mg/L
MT5	Two weeks before bloom GA_3 6.7 mg/L, full bloom GA_3 25 mg/L + SM 200 mg/L + CPPU 3 mg/L, 12 d after bloom GA_3 25 mg/L + CPPU 3 mg/L
MT6	Two weeks before bloom GA_3 6.7 mg/L, late flowering stage GA_3 25 mg/L + SM 200mg/L + CPPU 3 mg/L, 12 d after bloom GA_3 25 mg/L + CPPU 3 mg/L

Test items and methods

After grape ripening, the quality of fruits in each replicate was measured. Thirty berries were randomly clipped from the upper, middle and lower parts of each cluster. The weight of 30 berries was measured, the weight of each berry was calculated, and the seedless rate was calculated. Ten berries were randomly selected to measure the vertical diameter, transverse diameter, length and thickness of stems, soluble solid content, total acid content, flesh firmness without skin, pulling resistance and turgor pressure. The instruments used included electronic balance, vernier caliper, digital refractometer (PAL-1, Atago, Japan), pH meter (GMK-835, FG-WON, Korea), pointer push-pull meter (NK-30, Algol, Japan) and fruit hardness meter (KM-1, Takemura, Japan).

Seedless rate (%) = Number of seedless berries/Total berries ×100

Fruit shape index = Berry vertical diameter/Berry transverse diameter

Soluble solids to acidity ratio = Soluble solid content/Total acid content

Data analysis

SPSS 26 was used for statistics and analysis, and Duncan's new complex range method was used to test the difference significance ($P<0.05$).

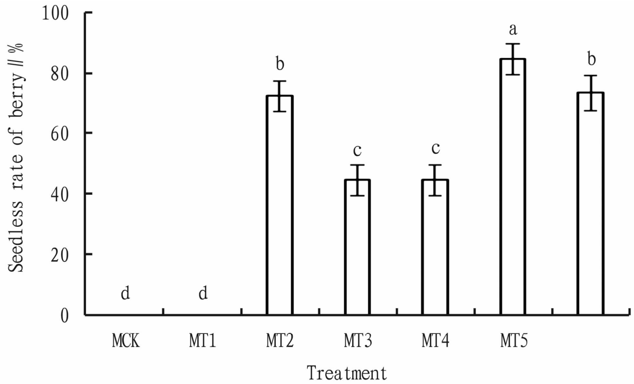
Results and Analysis

The seedless rate of 'Miguang' under different treatments

As shown in Fig. 1, the seedless rates of both the control and MT1 treatments were 0, which was significantly lower than those of other treatments. MT5 treatment had the highest seedless rate (84.44%), which was significantly higher than other treatments. The seedless rates of various treatments showed an order of MT5 > MT6 > MT2 > MT4 > MT3 > MT1 = MCK from high to low.

Effects of different treatments on cluster weight and single berry weight

As shown in Table 2, the cluster weight of 'Miguang' under different treatments ranked as MT3 > MT2 > MT5 > MT6 > MT4 > MCK > MT1. Except MT1, other treatments increased cluster weight. The cluster weight under MT2, MT3 and MT5 treatments significantly increased by 25%, 26.67% and 23.21%, respectively. Single berry weight showed an order of MT4 > MT3 > MT5 > MT2 > MT6 > MCK > MT1. Except MT1, other treatments increased the single berry weight, and MT4 significantly increased the single berry weight by 25.08%.



Different lowercase letters indicate significant difference at the 0.05 level among treatments.

Fig. 1 Effects of different treatments on the seedless rate of 'Miguang'

Effects of different treatments on the berry size and shape

Table 2 showed that the vertical diameter of berry under different treatments in the order of MT4 > MT3 > MT6 > MT2 > MCK > MT5 > MT1. Except MT1 and MT5, the berry vertical diameter under other treatments increased, among which MT3, MT4 and MT6 treatments significantly increased the vertical diameter by 4.96%, 10.52% and 4.14% compared with the control, respectively. The berry transverse diameter under different treatments ranked as MT4 > MCK > MT6 > MT2 > MT3 > MT5 > MT1. Except MT4 treatment, the berry transverse diameter under other treatments decreased significantly, and the berry transverse diameter under MT1, MT3 and MT5 treatments decreased significantly by 10.03%, 7.07% and 9.53% compared with control, respectively.

All the treatments significantly increased the berry shape index. Berry shape index under different treatments was MT3 > MT5

\> MT1 = MT4 > MT2 = MT6 > MCK.

Effects of different treatments on stem length and stem thickness

As shown in Table 2, stem length under different treatments ranked as MT5 > MT1 > MT2 > MT6 > MT4 > MCK > MT3. Except MT3 treatment, other treatments significantly increased stem length. Stem thickness diameter under different treatments was MT4 > MT5 > MT2 > MT3 > MT6 > MT1 > MCK. Stem thickness diameter significantly increased under each treatment, among which stem diameter under MT4 treatment was the greatest with 3.46 mm, with an increase of 89.07% compared with the control.

Table 2 Effects of different treatments on the characters of cluster, berry and stem

Treatment	Cluster weight//g	Berry weight//g	Berry vertical diameter//mm	Berry transverse diameter//mm	Berry shape index	Stem length//mm	Stem thickness//mm
MCK	549.30 ±47.76 c	9.13 ±0.16 b	25.58 ±0.87 cd	26.03 ±1.03 ab	0.98 ±0.04 c	9.08 ±0.96 cd	1.83 ±0.21 e
MT1	464.42 ±36.84 d	8.58 ±0.09 c	24.89 ±1.48 d	23.42 ±0.60 c	1.06 ±0.05 b	10.72 ±1.00 a	2.16 ±0.09 d
MT2	686.62 ±37.87 a	9.32 ±0.18 b	26.53 ±0.70 bc	25.23 ±0.66 b	1.05 ±0.03 b	10.70 ±0.90 a	2.85 ±0.19 c
MT3	695.78 ±68.02 a	9.44 ±0.18 b	26.85 ±1.33 b	24.19 ±1.02 c	1.11 ±0.02 a	8.38 ±0.85 d	2.67 ±0.24 c
MT4	568.27 ±47.35 c	11.42 ±0.24 a	28.27 ±0.90 a	26.52 ±0.76 a	1.06 ±0.03 b	9.78 ±0.41 bc	3.46 ±0.32 a
MT5	676.80 ±7.19 ab	9.33 ±0.11 b	25.24 ±0.76 d	23.55 ±1.45 c	1.07 ±0.06 ab	10.78 ±0.55 a	3.07 ±0.19 b
MT6	612.53 ±18.45 bc	9.26 ±0.20 b	26.64 ±1.21 b	25.52 ±1.36 b	1.05 ±0.05 b	9.83 ±0.67 b	2.23 ±0.19 d

Different lowercase letters in the same column indicate significant difference at 0.05 level among treatments. The same below.

Effects of different treatments on stem pulling resistance

The relevant index data of fruit internal quality is shown in Table 3. The stem pulling resistance under different treatments was MT4 > MT1 > MT2 > MT5 > MT3 > MCK > MT6, among which, the stem pulling resistance of MT1, MT2 and MT4 treatment was significantly greater than that of the control. And the stem pulling resistance of MT4 treatment was 7.71 N, with an increase of 56.07% compared with the control. There was no significant difference in stem pulling resistance between MT3 and MT5 treatment and control.

Effects of different treatments on berry turgor pressure

The berry turgor pressure under different treatments was MT2 > MT3 > MCK > MT1 > MT6 > MT5 > MT4, among which, the maximum berry turgor pressure was 18.2 N under MT2 treatment, which was significantly higher than that of the control. While there was no significant difference in berry turgor pressure between MT1, MT3 and MT6 treatment and the control.

Effects of different treatments on flesh firmness without skin

The flesh firmness without skin under different treatments was MT3 > MT2 > MT4 > MT6 > MT1 > MCK > MT5, among which, the flesh firmness without skin under MT2 and MT3 was significantly greater than that of the control, while the flesh firmness without skin treated with MT1, MT4 and MT6 was not significantly different with that of the control.

Effects of different treatments on soluble solids, total acid content and soluble solids to acidity ratio

The soluble solid content was MT1 > MCK > MT4 > MT3 > MT6 > MT5 > MT2. Among them, fruit soluble solid content under MT1 treatment was the highest, and there was no significant difference from the control, while soluble solid content under other treatments significantly decreased. Total acid content of fruits under different treatments was MT1 > MT2 > MT4 > MT3 = MT6 > MCK > MT5, and total acid content of fruit treated with MT1, MT2 and MT4 was significantly higher than that of control. The soluble solids to acidity ratio of fruits was MCK > MT5 > MT3 > MT6 > MT4 > MT1 > MT2, and soluble solids to acidity ratio of fruits in each treatment was significantly lower than that in the control.

Table 3 Effects of different treatments on the internal quality

Treatment	Pulling resistance (N)	Turgor pressure (N)	Flesh firmness without skin//kg	Soluble solid content//%	Total acid content//%	Soluble solids to acidity ratio
MCK	4.94 ±0.86 c	14.31 ±1.76 b	0.10 ±0.02 c	20.46 ±1.56 a	0.71 ±0.12 d	29.18 ±3.03 a
MT1	7.30 ±0.89 a	14.14 ±1.99 b	0.11 ±0.03 c	20.80 ±0.19 a	0.97 ±0.01 a	21.44 ±0.36 c
MT2	6.05 ±0.89 b	18.20 ±0.96 a	0.20 ±0.05 b	17.30 ±0.09 c	0.93 ±0.00 ab	18.60 ±0.17 d
MT3	5.00 ±0.70 c	14.98 ±1.10 b	0.47 ±0.08 a	18.50 ±0.26 bc	0.76 ±0.04 cd	24.38 ±1.06 bc
MT4	7.71 ±0.81 a	12.29 ±1.18 c	0.14 ±0.03 c	18.70 ±0.52 b	0.84 ±0.01 bc	22.26 ±0.64 c
MT5	5.60 ±0.76 bc	12.35 ±1.56 c	0.02 ±0.02 d	17.83 ±0.30 bc	0.69 ±0.02 d	25.85 ±0.55 b
MT6	3.88 ±0.55 d	13.66 ±1.01 b	0.12 ±0.03 c	18.20 ±0.65 bc	0.76 ±0.09 cd	23.93 ±2.42 bc

Comprehensive evaluation of the effects of different treatments on fruit quality

Through principal component analysis of the nine fruit quality indicators of 'Miguang' (Table 4), two principal components with eigenvalues >2 were extracted, and the cumulative contribution rates of variance were 61.35% and 86.48%, respectively, which could represent most of the information of the evaluation indicators.

According to the cumulative contribution rate analysis of principal components (Table 4), the contribution rate of the first principal component was 31.88%, including cluster weight, soluble solid content, berry shape index, flesh firmness without skin and berry turgor pressure. The second principal component contributed 29.48%, including total acid content, solid acid ratio, stem pulling resistance and single berry weight.

The comprehensive evaluation could directly reflect the effect of different treatments on the fruit quality of 'Miguang'. The higher the comprehensive score, the better the treatment effect. As shown in Table 5, comprehensive treatment effect was MT2 > MT3 > MT4 > MT1 > MT6 > MT5 > MCK, MT2 treatment had the best comprehensive effect.

Table 4 Eigenvalue, contribution rate and cumulative contribution rate of two PCAs

Factor	PC1	PC2
Eigenvalue	2.91	2.61
Contribution ratio	31.88	29.48
Cumulative contribution ratio	31.88	61.35
Cluster weight	0.91	-0.32
Soluble solid content	-0.85	0.08
Berry shape index	0.66	0.26
Flesh firmness without skin	0.65	0.10
Turgor pressure	0.46	0.37
Total acid content	-0.06	0.97
Soluble solids to acidity ratio	-0.39	-0.88
Pulling resistance	-0.31	0.78
Berry weight	0.10	0.13

Table 5 Comprehensive evaluation of the effects on the fruit quality under different treatments

Treatment	Cluster weight//g	Berry weight//g	Berry shape index	Pulling resistance (N)	Turgor pressure (N)	Flesh firmness without skin//kg	Soluble solid content//%	Total acid content//%	Soluble solids to acidity ratio	Z value	Rank
MCK	549.30	9.13	0.98	4.94	14.31	0.10	20.46	0.71	29.18	-1.173	7
MT1	464.42	8.58	1.06	7.30	14.14	0.11	20.80	0.97	21.44	0.023	4
MT2	686.62	9.32	1.05	6.05	18.20	0.20	17.30	0.93	18.60	1.065	1
MT3	695.78	9.44	1.11	5.00	14.98	0.47	18.50	0.76	24.38	0.526	2
MT4	568.27	11.42	1.06	7.71	12.29	0.14	18.70	0.84	22.26	0.163	3
MT5	676.80	9.33	1.07	5.60	12.35	0.02	17.83	0.69	25.85	-0.357	6
MT6	612.53	9.26	1.05	3.88	13.66	0.12	18.20	0.76	23.93	-0.248	5

Discussion and Conclusions

The period of the first time of hormone treatment was the key to induce grape seedlessness. Too early treatment could cause low seedless rate, small berry and curve spike-stalk; and too late treatment could cause less fruit set rate and low seedless rate[14]. The cluster weight and single berry weight of 'Miguang' treated two weeks before bloom were the smallest, and were significantly smaller than the control, indicating that premature hormone treatment was likely to cause smaller berries, and the related mechanism had not been reported. The seedless rate of 'Miguang' under the treatment two weeks before bloom GA_3 6.7 mg/L + full bloom (GA_3 25 mg/L + SM 200 mg/L + CPPU 3 mg/L) + two weeks after bloom (GA_3 25 mg/L + CPPU 3 mg/L) was the highest and significantly higher than other treatments, indicating that the hormone treatment during the bloom period played a key role in the seedlessness of 'Miguang'. In this study, compared with the control, the berry shape index after hormone treatment increased significantly, indicating that the effect of hormone treatment on promoting the longitudinal elongation of cells was significantly higher than that of lateral elongation. The results were consistent with Zhao[15] and Ma[16]. While the results of Bai[17] and Yan[18] indicated that GA_3 and CPPU treatments had no significant effect on berry shape index. The reason for the difference may be that different tree load or hormone use periods had different effects on berry shape index[15]. Zhu[19] thought that the use of exogenous plant hormones could increase the activity of phenylalanine ammoniase in berry stem, resulting in the accumulation of lignin, and thus increased the berry stem. He[20] pointed that GA_3, CPPU and SM had effects on grape stem thickening. In this study, the stem thickness treated was significantly greater than that of the control, and the results were consistent with previous studies. Except the treatment of two weeks before bloom (GA_3 15 mg/L + SM 200 mg/L) + two weeks after bloom (GA_3 25 mg/L + CPPU 3 mg/L), all other hormone treatments significantly reduced soluble solid content, which may be due to the use of exogenous hormones causing the increase of cluster weight, berry weight and fruit set, thus increasing plant load, resulting in insufficient nutrient supply.

Rational use of plant growth regulators can improve grape fruit quality, but plant growth regulators with improper concentration and frequency may cause fruit flavor deterioration, storage and transportation problems, but also lead to the increase of the risk of pesticide residue and production costs, so the rational use of plant growth regulators is crucial. In terms of fruit seedless rate, appearance traits, internal quality and cost saving, the treatment of one week before bloom (GA_3 20 mg/L + SM 200 mg/L) combined with two weeks after bloom (GA_3 25 mg/L + CPPU 3 mg/L) was relatively ideal, and the seedless rate was 72.22%. Because grape seedlessness technology is affected by variety characteristics, environmental temperature, moisture and cultivation measures, so it still takes time to make the seedlessness technology more perfect.

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to early yielding and high yield. (3) To produce seedless 'Huangjinmi' grapes, plant growth regulators such as gibberellin can be used, but attention should be paid to the influence of concentration on fruit quality. High concentrations of plant growth regulators will increase acidity, which is not conducive to the accumulation of flavor substances.

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