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GA3 and KCl Application as An Effort to Improve the Quality of Local Bali Grapes (*Vitis vinifera* L. var. Alphonso Lavallee)

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Abstract: The global demand for table grapes continues to rise, driven by consumer preference for sweet, high-quality, and seedless fruit. Local varieties such as Bali grape (Vitis vinifera L. var. Alphonso Lavallee) remain less competitive than imported grapes due to small berry size, high acidity, and seed presence. This study evaluated the optimal concentrations of gibberellic acid (GA3) and potassium chloride (KCl) and their interaction effects on Bali grape fruit quality. The experiment used a factorial randomized complete block design with two factors: GA3 at 0, 50, 100, and 150 ppm, and KCl at 0 and 300 g per plant, with five replications. The results showed that GA3 significantly affected all observed parameters. Application of GA3 at 150 ppm produced the longest clusters, largest berry diameter, highest berry weight, and greatest sugar content, while simultaneously reducing seed number and seed weight, indicating induced parthenocarpy. KCl application significantly increased sugar content and berry diameter but did not influence seed characteristics. A significant interaction between GA3 150 ppm and KCl 300 g per plant was observed, resulting in the highest number of berries per cluster and the highest sugar concentration. Combined GA3 and KCl application improved fruit quality and enhanced Bali grape competitiveness.

Keywords: Fruit quality; Gibberellic acid; Potassium chloride; Seedless grapes; Vitis vinifera

Introduction

Grapes (Vitis vinifera) are among the most popular fruit crops due to their high antioxidant content, abundant minerals, and rich nutritional value. Grapes are widely utilized in the beverage industry (wine), dried fruit production (raisins), and for fresh consumption (table grapes) (Ministry of Agriculture, 2024; Damayanti et al., 2025). The increasing utilization of grapes has led to a rise in demand. In 2023, national grape production reached 13,405 tons, while imports amounted to 10,901 tons with a value of US$ 369,782,228. Bali Province is the main grape-producing region in Indonesia, contributing approximately 89% (11,904 tons) of the national production (Ministry of Agriculture, 2024).

Bali grapes (Vitis vinifera L. var. Alphonso Lavallee), belonging to the black variety group and also known as Ribier, are a leading variety in Buleleng Regency. These grapes are generally consumed fresh or processed into wine (Astawa et al., 2015). However, the quality of Bali grapes still lags behind imported varieties due to their small berry size, slightly sour taste, and the presence of seeds. In fact, Bali grapes have relatively higher flavonoid content compared to other black varieties (Nile et al., 2013). Flavonoids act as antioxidants and contain catechins, epicatechins, and procyanidin polymers, which possess antibacterial properties (Petrussa et al., 2013; Damayanti et al., 2025). Therefore, quality improvement, particularly seed reduction, is essential to enhance their competitiveness.

Various technologies have been developed to produce seedless grapes, including tetraploid–diploid crossing, endosperm culture, pollen irradiation, genetic engineering, and plant growth regulator application (Sukamto, 2011). Among these methods, plant growth

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regulator application is considered more practical and economical for farmers. Gibberellin (GA3) is known to be effective in inducing parthenocarpy, increasing cluster length, and enlarging berry size (Astawa et al., 2023; Sun et al., 2023). Sari et al. (2023) reported that GA3 concentrations up to 100 ppm can induce parthenocarpy by inhibiting pollination and fertilization. Longer clusters also allow more optimal berry development, resulting in larger fruit (Mayadewi, 2023).

In addition to size, sweetness is an important indicator of grape quality. Potassium, particularly in the form of potassium chloride fertilizer, plays a role in photosynthate translocation, starch formation, and carbohydrate synthesis (Bhatt, 2022). Potassium chloride contains 60% K_2O and 40% Cl^- (Bhatt, 2022) and has been proven to enhance fruit sweetness, as indicated by increased total soluble solids in melon (Kamaratih & Ritawati, 2020).

Although the application of GA3 and potassium fertilizer has been widely reported, most studies focus on single-factor effects or are conducted on different grape cultivars and horticultural commodities. Evidence regarding the combined physiological response of GA3 and potassium nutrition on berry development, seed formation, and sugar accumulation in Bali grapes remains insufficient, particularly under local agroecological conditions.

The absence of integrated studies evaluating hormonal regulation and mineral nutrition simultaneously has limited the formulation of precise cultivation strategies for Bali grapes. Considering that berry enlargement, seed suppression, and sugar accumulation are interconnected processes regulated by hormonal balance and carbohydrate partitioning, an integrated approach is required to optimize fruit quality attributes in a single cultivation cycle. Clarifying the interaction between GA3 concentration and potassium supply is therefore crucial to provide a scientific basis for practical recommendations that are both effective and applicable at the farmer level.

This study aims to: (1) determine the optimal GA3 concentration to improve the quality of Bali grapes, (2) determine the optimal KCl dosage to improve the quality of Bali grapes, and (3) evaluate the interaction between GA3 and KCl on the quality of Bali grapes.

Method

Research Location and Period

This research was conducted in Kaliangat Village, Seririt District, Buleleng Regency, Bali, Indonesia, which has an agroclimate suitable for the cultivation of Vitis vinifera L. var. Alphonso Lavallee. The study lasted for four months, from January to April 2025, covering site preparation, treatment application, data collection, harvesting, and laboratory analyses.

Tools and Materials

The tools used included a hand sprayer for GA3 application, digital and analytical balances for weight measurements, a digital caliper for berry diameter, a pH meter, a hand refractometer, a camera, a measuring tape, graduated cylinders and pipettes, titration equipment, and a spectrophotometer. The materials consisted of Bali grape plants, gibberellin (GA3), potassium chloride (KCl) fertilizer, distilled water, an adhesive agent (Queen), and organic fertilizer.

Experimental Design and Procedures

This experimental study employed a factorial randomized block design (RBD) with two factors. The first factor was gibberellin (GA3) concentration at four levels: 0 ppm (G_0), 50 ppm (G_1), 100 ppm (G_2), and 150 ppm (G_3). The second factor was potassium chloride (KCl) dosage at two levels: without KCl (K_1) and 300 g/plant (K_2). The combination of these factors produced eight treatment combinations, each replicated five times, for a total of 40 experimental units. Each grape cluster served as the experimental unit. Data were analyzed using analysis of variance (ANOVA) based on the factorial RBD, and when significant effects were detected, mean separation was performed using the Least Significant Difference (LSD) test at the 5% probability level.

The research implementation procedure consisted of five main stages, namely grapevine selection, labeling, plant maintenance, application of GA_3 and KCl, and harvesting and post-harvest handling. All research activities are presented in the form of a flowchart, as shown in Figure 1.

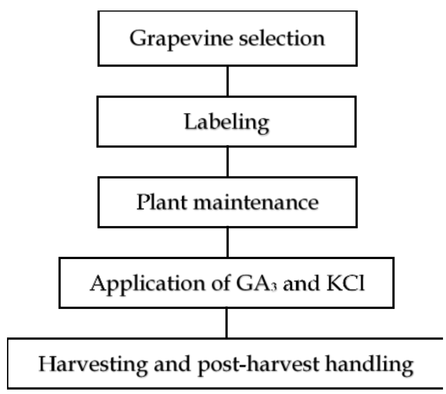

Figure 1. Research procedures flowchart

Grapevine selection

The grapevines selected as samples were Bali grapes (Vitis vinifera L. var. Alphonso Lavallee) that had reached full production with uniform age. The sampled vines were taken from the same vineyard area under the same ownership and with a uniform management history. These selection criteria were intended to ensure relatively homogeneous soil conditions, microclimate, and canopy density, thereby minimizing external factors that could influence the research results.

Labeling

Treatment labels were attached to the 12 grapevines used in this study to ensure accurate identification of each treatment combination. The main stem of each plant was marked with green tape, while grape branches were labeled with different colors according to the applied treatments. GA_3 treatments were color-coded as follows: 0 ppm (light blue), 50 ppm (yellow), 100 ppm (dark blue), and 150 ppm (white). Potassium chloride treatments were color-coded as control (green) and 300 g per plant (orange). This labeling system was implemented to facilitate data recording during treatment application, observation, and sample collection, thereby ensuring well-organized research procedures and improving the accuracy of data analysis.

Plant maintenance

The maintenance of sample plants was carried out by applying proper and standardized grape cultivation Standard Operating Procedures (SOPs) to support optimal plant growth and development. Maintenance activities included regular weed control to reduce competition for nutrients, water, and light. In addition, fertilization was conducted using cattle manure at a rate of 25 kg per plant to ensure adequate nutrient availability, improve soil fertility and structure, and create favorable growing media conditions that support plant productivity. Pest and disease control was implemented using environmentally friendly methods in accordance with established agronomic standards to maintain plant health without causing adverse environmental impacts. Irrigation was performed regularly to maintain soil moisture, ensuring sufficient water supply and promoting optimal plant growth.

Application of GA_3 and KCl

Selected sample plants were treated with gibberellin (GA3) and potassium chloride (KCl) to enhance plant growth, induce seedless fruit formation, and improve overall fruit quality. Gibberellin solutions were prepared by first making a 1,000 ppm stock solution, which was subsequently diluted with distilled water to obtain application concentrations of 0, 50, 100, and 150 ppm. GA_3 was applied in two stages, namely at anthesis and 22 days after anthesis, which are critical periods for grape flower and fruit development. The treatments were applied by spraying directly onto the flower clusters to ensure uniform distribution and effective absorption. Applications were conducted in the morning under cooler temperatures and higher humidity to maximize uptake and minimize evaporation.

Potassium chloride was applied as a supplementary fertilizer through soil application around the root zone. Circular furrows were made approximately 50 cm from the plant base, into which the KCl fertilizer was evenly broadcast and then covered with soil. KCl application was carried out in two stages, before veraison (22 days after anthesis) and at the veraison stage. These application timings were intended to optimize nutrient uptake, support fruit development, and enhance fruit quality during the transition from vegetative growth to fruit ripening.

Harvesting and post-harvest handling

Harvesting was carried out by manually picking grape clusters that had reached optimal maturity according to research standards. Fruit maturity was indicated by changes in skin color from green to reddish-purple, softer flesh texture with optimal sugar content, and a decrease in acidity to levels characteristic of ripe grapes. Harvesting was conducted selectively, with only fully mature fruits being picked, and was performed at seven-day intervals to ensure optimal fruit quality.

Postharvest handling involved a sorting process to classify grapes based on quality. Sorting was conducted manually by evaluating fruit color, size, and physical condition, followed by water flotation to separate well-filled fruits from hollow or defective ones. Selected grape samples were subsequently analyzed in the laboratory to determine quality parameters, including sugar content, vitamin C, anthocyanin content, and potassium levels, in order to evaluate the effects of the treatments on final fruit quality.

Result and Discussion

Cluster Length (cm)

The results of this research showed that the average cluster length of Bali grapes under GA3 treatments ranged from 15.20 to 20.10 cm, with the highest value obtained from the 150 ppm GA3 treatment (20.10 cm), which was significantly different from other treatments. This indicates the most pronounced effect in elongating the clusters. Treatments with 50 ppm and 100 ppm GA3 produced average cluster lengths of 19.10 cm and 19.50 cm, respectively, but were not significantly different from each other. In contrast, the control (without GA3 application) produced the shortest average cluster length (15.20 cm), which was significantly shorter than all GA3 treatments (Table 1).

GA3 is known to stimulate cell elongation and cell division in the grape rachis, resulting in longer clusters and more dispersed berries. This mechanism increases the space between berries and prevents overly compact clusters (Gao et al., 2020).The effect is related to the nature of GA3 as a gibberellin hormone, which is naturally synthesized in young tissues such as young leaves, root tips, and germinating seeds, but in external applications is used in the form of white crystals soluble in ethanol and slightly soluble in water. Physiologically, GA3 works by enhancing the activity of hydrolytic enzymes such as α-amylase, which breaks down starch reserves into simple sugars to provide energy for cell division and elongation (Sponsel & Hedden, 2010). In addition, GA3 modulates the expression of cell wall-related genes, including expansin and xyloglucan endotransglycosylase, which loosen the cell wall to facilitate elongation (Yang et al., 2008).

Table 1. Mean cluster length and berry diameter of local Bali grapes as affected by GA_3 and KCl treatments based on the Least Significant Difference (LSD) test at the 5% level

Treatment	Cluster Length (cm)	Berry Diameter (mm)
Tanpa GA3	15.20 ± 0.63 c	15.90 ± 1.20 c
GA3 50 ppm	19.10 ± 0.74 b	17.17 ± 1.25 b
GA3 100 ppm	19.50 ± 0.71 ab	18.12 ± 1.02 a
GA3 150 ppm	20.10 ± 0.88 a	18.48 ± 0.65 a
LSD 5%	0.62	0.77
Without KCl	18.50 ± 1.88	17.04 ± 1.65 a
KCL 300 g	18.45 ± 2.31	17.80 ± 1.08 a
LSD 5%	-	0.54

Studies on Bali grapes have shown that GA3 application prior to flowering can increase cluster length, although individual berry size may decrease depending on the dosage (Astawa et al., 2015). This is consistent with the observed phenomenon in this experimental study, where higher GA3 concentrations resulted in increased cluster length. However, excessive concentrations may lead to an imbalance in photosynthate distribution, potentially reducing berry size or affecting seed number.

Meanwhile, KCl application had no significant effect on cluster length in Bali grapes. This may be attributed to the primary role of potassium in physiological processes related to fruit quality formation, such as regulating osmotic pressure, activating enzymes, and facilitating sugar and nutrient transport via the phloem, rather than directly influencing vegetative organ growth or rachis elongation (Marschner, 2012). In the early stages of cluster development, growth is more strongly influenced by plant growth hormones such as gibberellins and auxins, so additional KCl did not produce a noticeable response. Furthermore, if potassium status in the soil is already sufficient, supplemental KCl application will not significantly increase cluster length because the nutrient requirement has already been met (Zörb et al., 2014).

Berry Diameter (mm)

The results of this research showed that the application of GA3 and KCl each had a significant effect on the berry diameter of Bali grapes. GA3 treatments produced mean berry diameters ranging from 15.90 to 18.48 mm, with GA3 at 150 ppm producing the largest diameter (18.48 mm ± 0.65), which was not significantly different from GA3 at 100 ppm (18.12 mm ± 1.02), but significantly larger than the control (15.90 mm) and GA3 at 50 ppm (17.17 mm) (Table 1). Meanwhile, the KCl treatment that produced the largest berry diameter was 300 g KCl (17.80 mm ± 1.08), which was not significantly different from the control (17.04 mm ± 1.65).

GA3 is a plant growth hormone belonging to the gibberellin group that plays an important role in the fruit enlargement phase by extending the period of cell growth, increasing the fruit's capacity as a sink for photosynthates, and enhancing sugar and assimilate uptake through increased activity of carbohydrate-metabolizing enzymes such as invertase and sucrose synthase (Sawant et al., 2024). This hormone also promotes water accumulation in fruit cells by increasing osmotic pressure, thereby expanding cell volume and enlarging berry diameter (Wang et al., 2013), in contrast to its effect on cluster length, which is more related to rachis elongation.

In the present research, GA3 at 150 ppm was proven to be optimal in increasing berry diameter without causing sugar dilution. This finding is consistent with previous research showing that GA3 at 100–150 ppm effectively increases fruit size and induces parthenocarpy in 'Kyoho' grapes Sun et al. (2023) and 'Cabernet Sauvignon' Gao et al. (2020). However, in Bali grapes, GA3 at 100 ppm increased berry diameter but had limited effects on seed number (Astawa et al., 2015). Table 2 also indicates that KCl affected the berry diameter of Bali grapes. KCl is an inorganic fertilizer containing approximately 60% K_2O and 40% Cl^- (Taisa et al., 2021), with potassium playing a role in osmotic regulation of cells, enzyme activation, turgor maintenance, and enhancing sugar transport through the phloem, thereby facilitating more efficient photosynthate allocation to the fruit (Marschner, 2012; Wu et al., 2024). These mechanisms support fruit enlargement, weight gain, and sugar accumulation. Previous research reported that 300 g KCl per plant increased °Brix in melon up to 14 (Kamaratih & Ritawati, 2020) and enhanced both diameter and sugar content in sweet orange (Fernandez & De Guzman, 2020). In this research, although KCl did not affect cluster length, the application of 300 g KCl increased berry diameter and sugar content, particularly when combined with GA3 at 150 ppm, confirming its more dominant role during the fruit filling and ripening phases compared to cluster length formation, which is more influenced by hormonal factors.

Number of Berries per Cluster

The results of this research showed a significant interaction between GA3 and KCl on the number of berries per cluster of Bali grape, in which the treatment of 150 ppm GA3 combined with 300 g KCl produced the highest number of berries per cluster, with an average of 60.40 berries, significantly higher than other treatments (Table 2).

Table 2. Mean number of berries per cluster as affected by GA_3 and KCl treatments based on the LSD test at the 5% level

Treatment	Number of Berries per Cluster		Means
	Without KCL	KCl 300 g/plant	
GA3 0 ppm	27.60 ± 12.72 a C	17.20 ± 7.60 a C	22.20 C
GA3 50 ppm	32.40 ± 12.64 a BC	38.20 ± 14.96 a B	35.30 B
GA3 100 ppm	39.80 ± 12.13 b AB	55.40 ± 9.34 a A	47.60 A
GA3 150 ppm	49.00 ± 11.34b A	60.40 ± 10.78 a A	54.70 A
Means	37.20 b	42.80 a	
LSD 5% GA3			7.81
LSD 5% KCl			5.52
LSD 5% Interaction			11.04

Note: Mean values followed by the same lowercase letters within the same row and the same uppercase letters within the same column indicate no significant differences according to the Least Significant Difference (LSD) test at the 5% significance level ($P < 0.05$).

The interaction between 150 ppm GA3 and 300 g KCl increased the number of berries per cluster because both treatments have complementary mechanisms during the flowering and fruit set phases. GA3, a plant growth hormone belonging to the gibberellin group, plays a role in regulating the transition from the vegetative to the reproductive phase by enhancing the expression of genes that control flower initiation and reproductive organ development (Mutasa-Göttgens & Hedden, 2009). Application of GA3 during the early flowering stage can increase the number of fertile flowers, reduce flower abortion, and extend flower viability, thereby increasing the probability of fruit formation (Kapłan et al., 2019).

Meanwhile, KCl provides potassium in a readily available form, which is essential in the processes of pollination and fruit formation. Potassium plays a role in pollen tube growth, cell division in the ovary, and maintenance of ovary turgor, thus increasing the success rate of fertilization (Bednarz et al., 1998). Potassium also supports nitrogen metabolism and protein synthesis in reproductive organs, which contributes to early fruit development (Zahoor et al., 2017).

Previous studies on Vitis vinifera cv. Crimson Seedless showed that the application of GA3 combined with potassium fertilization increased the number of berries per cluster by improving flowering synchronization and optimizing nutrient distribution to flowers (Mohamed et al., 2022). The present research confirms that the combination of 150 ppm GA3 and 300 g KCl in Bali grape can maximize the number of berries per cluster through the synergy between improved flowering quality and the availability of essential nutrients during the fruit set phase.

Cluster Weight (g)

The results showed that GA3 application had a significant effect on the cluster weight of Bali grapes, with the highest average cluster weight obtained from the 150 ppm GA3 treatment (179.90 g ± 72.27), which was significantly different from other treatments. In contrast, KCl application did not have a significant effect on the cluster weight of Bali grapes (Table 3).

Table 3. Mean cluster weight as affected by GA_3 and KCl treatments based on the LSD test at the 5% significance level

Treatment	Cluster Weight (g)
Without GA3	80.00 ± 36.76 c
GA3 50 ppm	109.70 ± 49.83 bc
GA3 100 ppm	136.20 ± 52.91 b
GA3 150 ppm	179.90 ± 72.27 a
LSD 5%	34.08
Without KCl	142.25
KCL 300 g	110.65

The 150 ppm GA3 treatment increased cluster weight because its active component, gibberellin, plays a role in regulating cell division and enlargement during the fruit development phase, while also extending the fruit filling period. This extended filling duration allows more time for biomass accumulation in each berry, thereby increasing the total cluster weight. GA3 also influences assimilate allocation by directing photosynthates to the main sink organ—here, the fruit cluster—through the enhancement of enzyme activity involved in carbohydrate transport and metabolism (Kapłan et al., 2019). This effect not only increases the size of each berry but also improves the number of berries that reach optimal maturity at harvest.

Meanwhile, the non-significant effect of KCl on cluster weight indicates that, under the field conditions of this study, the availability of potassium in the soil was already sufficient to meet the plant's physiological requirements. Although potassium is important in the processes of fruit enlargement and sugar accumulation, it will not have a pronounced impact on cluster weight if the primary limiting factor lies in hormonal regulation or fruit sink capacity (Mpelasoka et al., 2003).

Previous studies on Vitis vinifera cv. Italia have shown that the application of 100–150 ppm GA3 can increase cluster weight by up to 25% compared with the control through a combination of berry enlargement and reduced fruit abortion rates (Pahi et al., 2020). Similar results were reported for Vitis vinifera cv. Thompson Seedless, where GA3 application alone had a greater effect on cluster weight than potassium fertilization in soils with high K fertility status (Wang et al., 2013). These findings support the results of the present study, indicating that growth hormone factors play a more decisive role in increasing cluster weight than potassium supplementation under adequate soil K conditions.

Berry Weight (g)

The results indicated that both GA3 and KCl treatments had a significant effect on the average berry weight of Bali grape. The 150 ppm GA3 treatment produced the highest mean berry weight (46.50 g ± 12.04), which was significantly different from the other treatments. Meanwhile, the treatment without KCl application yielded the highest berry weight (42.80 g ± 13.95), which was significantly different from the 300 g KCl per plant treatment (Table 4).

The increase in berry weight under the 150 ppm GA3 treatment can be attributed to its active compound, gibberellin, which extends the cell enlargement phase and delays fruit senescence, thereby prolonging the period for biomass accumulation. During this phase, GA3 enhances the expression of genes regulating structural protein synthesis and carbohydrate-metabolizing enzymes, resulting in increased cell volume and fruit tissue density (Chauhan et al., 2020). GA3 also promotes the formation of thicker secondary cell walls, producing denser fruits with greater weight, even when the visual size does not increase proportionally.

Conversely, the 300 g KCl treatment reduced berry weight. KCl contains approximately 60% K_2O and 40% Cl^- (Taisa et al., 2021), where potassium at optimal levels supports fruit enlargement by regulating osmotic pressure and activating enzymes. However, excess potassium may cause nutrient antagonism, particularly inhibiting the uptake of magnesium (Mg^{2+}) and calcium (Ca^{2+}), which are essential for cell wall formation and membrane stability (Havlin et al., 2021). This condition may decrease fruit tissue density and ultimately reduce final berry weight, even when water content remains high.

Previous research on Vitis vinifera cv. Superior Seedless reported that GA3 application at 100–150 ppm significantly increased berry weight through pulp tissue enlargement (Peppi & Fidelibus, 2008). Similarly, studies on melon have shown that excessive potassium fertilization can decrease fruit weight due to impaired calcium uptake, leading to less dense fruit tissues (Kanai et al., 2011). The findings of this study are consistent with these reports, where GA3 exerted a positive effect on berry weight, while excessive KCl application tended to reduce it due to nutrient imbalance.

Table 4. Mean berry weight, number of seeds, and seed weight of local Bali grapes as affected by GA3 and KCl treatments based on the LSD test at the 5% level

Treatment	Berry Weight (g)	Seed Number	Seed Weight (g)
Without GA3	30.40 ± 11.30 d	25.20 ± 3.12 a	1.74 ± 0.19 a
GA3 50 ppm	34.00 ± 13.41 c	14.90 ± 1.91 b	1.23 ± 0.14 b
GA3 100 ppm	39.40 ± 13.11 b	10.90 ± 1.79 c	0.76 ± 0.14 c
GA3 150 ppm	46.50 ± 12.04 a	1.90 ± 2.77 d	0.08 ± 0.10 d
LSD 5%	3.57	1.66	0.11
Without KCl	42.80 ± 13.95 a	13.75 ± 8.77	0.93 ± 0.64
KCL 300 g	37.20 ± 20.09 b	12.70 ± 9.02	0.98 ± 0.65
LSD 5%	2.52	-	-

Seed Number

The results of this study indicated that GA3 application had a significant effect on the seed number of Bali grape berries, with the 150 ppm GA3 treatment producing the lowest seed number (1.90 ± 2.77), which was significantly different from the other treatments. In contrast, KCl application did not have a significant effect on the seed number of Bali grape berries (Table 4).

The application of GA3 at 150 ppm reduced seed number because its active component, gibberellin, can induce ovary development without normal fertilization (parthenocarpy). This mechanism occurs through stimulation of cell division and enlargement in the ovary, as well as upregulation of genes involved in fruit growth, such as GA20-oxidase and expansin, even when fertilization does not proceed completely (Liu et al., 2023). Moreover, GA3 can alter the balance of endogenous hormones, including reducing auxin and cytokinin concentrations in the ovary, which are required for embryo development, thereby leading to suboptimal seed formation (Shinozaki et al., 2015). As a result, the fruit continues to develop but contains few or no seeds.

In contrast to GA3, KCl primarily serves as a source of potassium and chloride, supporting osmotic regulation, carbohydrate metabolism, and enzymatic activity during fruit filling (Zörb et al., 2014). However, these functions do not directly regulate pollination or embryo development, which explains the negligible and non-significant effect of KCl on seed number in the present study.

Recent research on Vitis vinifera cv. Thompson Seedless reported that pre-anthesis GA3 application can reduce pollen viability and inhibit seed development, resulting in parthenocarpic fruit (Feng et al., 2025). Similarly, studies on pepper have shown that GA3 treatment induces seedless fruit formation through upregulation of gibberellin-related genes and downregulation of seed formation genes (Liu et al., 2023). These findings support the results of the present study, in which 150 ppm GA3 significantly reduced seed number, whereas KCl application had no meaningful effect.

Seed Weight (g)

The results showed that GA3 treatment had a significant effect on the variable of seed weight per 10 berries of Bali grape, with the best result obtained from the GA3 150 ppm treatment (0.08 g ± 0.10), which was significantly different from the other treatments. Meanwhile, KCl treatment had no significant effect on seed weight per 10 berries (Table 4).

Application of GA3 at 150 ppm reduced seed weight because its active compound, gibberellin, is capable of inducing parthenocarpic fruit set or disrupting normal seed development after fertilization. At the physiological level, GA3 alters the pattern of cell division and differentiation in embryo and endosperm tissues, resulting in abortive or small-sized seeds (Li et al., 2024). In addition, increased levels of exogenous gibberellin can suppress cytokinin biosynthesis and its distribution to developing seed tissues, which is crucial for embryonic cell division and the accumulation of storage reserves (Williams & Letham, 1969). This effect is often accompanied by changes in assimilate allocation, with most photosynthates being directed to pericarp tissue for fruit enlargement rather than to the seeds.

KCl, as a source of potassium and chloride, plays a role in osmotic regulation, enzyme activation, and carbohydrate transport (Zörb et al., 2014). However, at the seed developmental stage, this role is secondary, as seed weight formation is more strongly influenced by hormonal regulation and successful fertilization. Studies on Prunus persica have shown that adequate potassium availability supports seed filling but cannot compensate for hormonal effects that inhibit embryo development (Manjarrez et al., 2023). This finding is consistent with the present study, in which KCl had no significant effect on seed weight.

Research on Vitis vinifera cv. Thompson Seedless by Cheng et al. (2013) reported that GA3 application before anthesis can significantly reduce seed weight due to decreased ovule viability and increased seed abortion. Meanwhile, studies on Camellia oleifera have shown that although potassium fertilization improves carbohydrate metabolism in seeds, its effect is not significant when disturbances occur during fertilization (Yang et al., 2008).

Sugar Content (°Brix)

The results showed that the interaction between GA3 and KCl treatments had a significant effect on the sugar content of Bali grape. The combination of GA3 at 150 ppm and KCl at 300 g produced the highest sugar content (20.60 °Brix ± 1.14), which was significantly different from the other treatments, except for GA3 at 50 ppm combined with KCl at 300 g (20.20 °Brix ± 1.30) (Table 8).

Table 8. GA3 at 50 ppm combined with KCl at 300 g (20.20 °Brix ± 1.30)

Treatment	Sugar Content (°Brix) Without KCL	KCl 300 g/plant	Means
GA3 0 ppm	14.20 ± 0.84 a C	14.60 ± 1.34 a B	14.40 C
GA3 50 ppm	16.80 ± 1.10 b B	20.20 ± 1.30 a A	18.50 B
GA3 100 ppm	18.60 ± 0.89 a A	19.60 ± 1.14 a A	19.10 AB
GA3 150 ppm	18.20 ± 1.79 b AB	20.60 ± 1.14 a A	19.40 A
Means	16.95 b	18.75 a	
LSD 5% GA3			0.79
LSD 5% KCl			1.12
LSD 5% Interaksi			1.58

Note: Mean values followed by the same lowercase letters within the same row and the same uppercase letters within the same column indicate no significant differences according to the Least Significant Difference (LSD) test at the 5% significance level ($P < 0.05$).

The combination of GA3 at 150 ppm and KCl at 300 g increased fruit sugar content because both treatments influence the ripening phase through complementary physiological mechanisms. GA3, as an active gibberellin, can delay leaf senescence and maintain photosynthetic capacity for a longer period, thereby sustaining assimilate supply to the fruit during the ripening stage (Li et al., 2024). The prolonged photosynthetic activity contributes to higher sucrose reserves, which are subsequently hydrolyzed into glucose and fructose during ripening. Furthermore, GA3 also modulates the expression of genes related to sugar metabolism, such as cell wall invertase and sucrose phosphate synthase, which directly contribute to the accumulation of simple sugars in fruit tissues (Li et al., 2024).

Meanwhile, KCl, as a source of potassium (±60% K_2O) and chloride, plays a role in maintaining the osmotic gradient necessary for sugar transport through the phloem (Zörb et al., 2014). Potassium enhances the sink capacity of the fruit by strengthening phloem loading and accelerating sugar translocation from leaves to fruits (Kanai et al., 2011). Adequate potassium availability has also been shown to improve the balance of carbohydrate metabolism enzymes during the final ripening stage, thereby increasing total soluble solids.

A study on Vitis vinifera cv. Crimson Seedless reported that pre-veraison GA3 application followed by potassium fertilization increased sugar content to 15–18 °Brix compared to the control, which only reached 13–14 °Brix (Ibrahim et al., 2021). Another study on melon demonstrated that the combined application of GA3 and KCl significantly accelerated sugar accumulation and improved fruit flavor quality by enhancing photosynthetic efficiency and sugar transport (Eshghi et al., 2025). These findings are consistent with the present study, in which the combination of GA3 at 150 ppm and KCl at 300 g resulted in the highest sugar content compared to single treatments.

Conclusion

The application of GA3 had a significant effect on improving the quality of Bali grapes, particularly at a concentration of 150 ppm. This treatment produced longer clusters, larger berry diameter and weight, fewer seeds and lower seed weight per berry, as well as increased fruit sugar content. Meanwhile, the application of 300 g KCl alone did not show a significant effect on most parameters; however, in combination with 150 ppm GA3, it exhibited a positive interaction, especially in increasing the number of berries per cluster and fruit sugar content. The combination of 150 ppm GA3 and 300 g KCl can be recommended as the most effective treatment for enhancing the quality of Bali grapes in terms of size, sweetness, and seed reduction.

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Conflict of Interest

The authors declare no conflict of interest.

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