Prolonging shelf life of flame seedless table grapes with pre-harvest calcium and magnesium treatment

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Abstract. Nutritional balance methods serve as effective tools for predicting the nutritional status of grapevines and mitigating issues related to nutrient excess or deficiency, thereby influencing yield, fruit quality, and market longevity. This study investigates the effects of pre-harvest applications of calcium (Ca) and magnesium (Mg) at varying concentrations, individually and in combination, on grape quality. Pre-harvest foliar applications were conducted six times across three key phenological stages: pre-bloom, post-bloom, and fruit set. Treated clusters were stored in refrigerated conditions (10 °C, 90–95% relative humidity) for 12 days, during which fruit quality was evaluated at harvest and throughout the marketing period. The results demonstrated that prolonged market storage increased decay, weight loss, Soluble solids content (S.S.C.), total sugar content, shattering, berry adherence, and respiration rate, while firmness, total acidity, vitamin C content, and total phenols decreased. All treatments enhanced cluster weight and yield at harvest. The most effective treatment for maintaining cluster quality under market conditions was the combined foliar application of magnesium oxide (MgO, 0.056%) and calcium chloride ($CaCl_2$, 0.016%). This treatment significantly reduced physiological weight loss, berry shattering, and decay percentage, thereby preserving the marketability of 'Flame Seedless' grapes.

1 Introduction

Grapes (*Vitis vinifera* L.) belong to the family Vitaceae and are native to the riverbanks of Asia, North America, and Europe. The crop holds significant importance due to its high nutritional value, taste, versatility in usage, and the superior economic returns it provides to farmers. Grapes are cultivated extensively across the globe, including in Egypt, where they are grown on an area of approximately 85,240 hectares, yielding a total production of 1,435,000 tons.

In Egypt, "Flame Seedless" is a prominent table grape variety valued for both local consumption and export. This cultivar is characterized by its early ripening, high productivity, and excellent sensory qualities. The berries are round, firm, and crunchy with a bright red color, superior flavor, and a high content of soluble solids at harvest. Furthermore,

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its early maturation makes it suitable for accessing the European Union market during peak price periods.

Despite its economic importance, the postharvest life of table grapes is challenged by significant losses. These losses can occur at harvest due to suboptimal quality attributes such as inadequate size or color, as well as during postharvest handling due to spoilage. Postharvest issues, including berry shattering, softening, stem discoloration, and fungal rots, are major contributors to production losses. Such problems often lead to the rejection of a substantial percentage of fruits prior to consumption, causing significant economic losses to producers and stakeholders along the marketing chain.

The market value of "Flame Seedless" grapes is highly dependent on their visual appeal, particularly the uniformity of berry color, cluster size and shape, and firmness. Berry firmness is a critical determinant of consumer acceptance, along with the absence of defects such as decay, cracked berries, shattering, stem browning, shriveling, sunburn, or dried berries. Additionally, high resistance to transport damage is essential for maintaining quality during distribution. Therefore, minimizing postharvest losses and enhancing the shelf life of "Flame Seedless" grapes are crucial for ensuring their economic viability and market success.

Modern table grape production is characterized by its alignment with market requirements, focusing on improving grape quality by optimizing nutrient management to influence physiological processes within the plant system. Adequate nutrition is essential for maintaining proper growth and achieving desirable levels of yield and fruit quality.

Calcium (Ca^{2+}) plays a pivotal role in fruit formation, development, and quality. Most calcium in plant tissues is found in the cell wall as calcium pectate, which is associated with fruit firmness, the prevention of physiological disorders related to cell wall integrity, and other quality attributes. Calcium deficiency in grapes can result in physiological disorders such as blossom end rot. Numerous studies have demonstrated that calcium application significantly enhances yield and fruit quality.

It is reported that pre-harvest sprays of calcium chloride ($CaCl_2$) at concentrations of 0.25%, 0.50%, and 1.0% applied at the fruit-set and véraison stages of 'Flame Seedless' grapes improved yield, increased bunch weight, and enhanced fruit quality [1]. Foliar calcium applications were particularly effective in reducing berry decay, cracking, wrinkling, and shattering. Similarly, it is proved that the application of calcium nitrate ($Ca(NO_3)_2$) at 30 $kg \cdot ha^{-1}$ via drip irrigation during the swelling and véraison stages significantly increased grape production and improved fruit quality. These applications resulted in reduced Soluble solids content (S.S.C.), increased titratable acidity, higher anthocyanin content, and elevated levels of total phenols, reducing sugar, and soluble sugar content.

The importance of calcium in improving grape berry quality and storage potential has been further corroborated by (Perennia, 2019), who highlighted its role in enhancing berry firmness and extending shelf life. Pre-harvest application of AMINOQUELANT-Ca to 'Superior' grapes increased fruit weight and yield at harvest. During storage at 0 °C for eight weeks, this treatment reduced decay, weight loss, and delayed changes in firmness, berry adherence, total acidity, total soluble solids, vitamin C, total sugars, and respiration rate compared to untreated controls.

Additionally, pre-harvest calcium sprays improved the antioxidant potential of grape berries by regulating flavonoid metabolic pathway-related genes, thereby reducing the incidence of berry cracking [2]. Confirmed that foliar applications of $Ca(NO_3)_2$ and $CaCl_2$ enhanced calcium concentrations in internal tissues, contributing to prolonged shelf life. Further highlighted that calcium foliar application positively influenced fruit mass, reduced fresh mass loss, maintained firmness, preserved high total acidity, and minimized physiological disorders during cold storage and postharvest handling of various fruits.

Magnesium (Mg^{2+}) is an essential nutrient for plant growth, playing critical roles in cellular processes such as chlorophyll production, ATP synthesis within chloroplasts, protein synthesis, and the regulation of reactive oxygen species homeostasis [3]. Additionally, magnesium has been identified as a key factor in flowering induction. Magnesium deficiency during the growing season adversely affects photosynthetic efficiency, leading to reduced plant performance.

Research has demonstrated that magnesium applications can significantly enhance crop yield and fruit quality. For instance, it was found that foliar sprays of magnesium sulfate and magnesium nitrate (1%) applied three times annually (in July, August, and September) resulted in significant improvements in the yield, fruit weight, diameter, length, peel and pulp thickness, juice volume, Soluble solids content (S.S.C.), total acidity (TA), SSC/TTA ratio, and ascorbic acid content in "Murcott" mandarin. Similarly, it is observed that applying magnesium oxide (MgO) at 150 g per plant enhanced fruit yield and quality in navel orange by increasing pulp sugar content—particularly sucrose—and promoting peel coloration.

The benefits of magnesium application extend to grapevine cultivation as well. Known that foliar applications of magnesium-nano fertilizers effectively alleviated magnesium deficiency in ‘Superior Seedless’ vines grown in saline sandy soils, significantly improving bunch quality. Additionally, it is reported that combined applications of calcium, magnesium, and molybdenum enhanced vegetative growth traits, yield, and quality in 'Flame Seedless' grapes [4].

. **Fruit Material:**

The present study was conducted during the 2022 and 2023 growing seasons on Flame Seedless grapevines (*Vitis vinifera* L.) in a privately owned vineyard situated in the El-Nubaria region, Behera Governorate, Egypt. The grapevines, aged 12 years, were spaced 2.0 m apart within rows and 3.0 m between rows, cultivated in sandy loam soil under a drip irrigation system. The vines were trained on a Spanish trellis system. Standard cultural practices commonly implemented for table grape production were uniformly applied throughout the experimental period.

To ensure experimental consistency, the vines selected were healthy, representative of the cultivar, and uniform in vigor and morphology. Pruning was performed annually during the last week of December, with each vine pruned to include six buds per cane and four renewal spurs (two buds per spur), resulting in a total of 80 buds per vine. During the growing season, cluster management was conducted when the average berry diameter reached approximately 10 mm. Each vine retained 34 clusters, with cluster rachises tipped to 10 cm, while excess clusters were removed.

A total of 135 vines were selected for the experiment, organized in a completely randomized design (CRD). The vines were divided into nine treatment groups, each replicated three times, with each replicate consisting of five vines. Foliar spraying treatments were applied to both vegetative growth and clusters, incorporating BB5, a wetting agent, at a concentration of 0.05% in all spray solutions. Applications were carried out to the point of runoff at a rate of 2 liters per vine.

Experimental Design:

The experiment consisted of nine treatments. Each treatment had three replicates, with each replicate comprising five vines (9 treatments x 3 replicates x 5 vines = 135 vines per season). The experiment was arranged in a randomized complete block design (RCBD) for both seasons.

Table 1. Soil characteristics of flame seedless

Physical properties	Value	Chemical analysis	Value	Anion and Cation	Value
Texture	Sandy Loam	pH	7.41	Ca^{++} mg/100g	12.3
Clay %	11.6	E.C. µS/cm	519	Mg^{++} mg/100g	1.97
Silt %	20	Organic Matter%	1.28	K^{+} mg/100g	0.62
Sand %	68.4	CaCO3 %	5.05	Na^{+} mg/100g	1.07
Fine Sand %	57.7	Nitrogen (N) mg/kg	826		
Coarse Sand %	10.7				

Table 2. Chemical analysis of water used for irrigation

Physicochemical properties	Value	Cations	Value	Anions	Value
E.C. ds/m	0.98	Ca mg/l	66	HCO mg/l	203
ph	7.3	Mg mg/l	22	Cl mg/l	73
		K mg/l	14	Sulphates mg/l	65
		Na mg/l	108	Nitrates mg/l	0.7

The chemical analysis of the soil, the compost and the water were carried out at laboratory of Soil and Water Research Institute, Agricultural Research Center

A total of six pre-harvest treatments were applied during three distinct phenological stages:

1. Pre-bloom stage: Two applications were conducted prior to floral bloom, during early March.
2. Post-bloom stage: Two applications were carried out immediately following floral bloom, in early April.
3. Fruit set stage: Two applications were performed approximately one month after fruit set, at the end of April.

Calcium was sourced from Stopit Calcium, while magnesium was provided by magnesium sulfate ($MgSO_4$).

Pre harvest Treatments

1	**CONTROL**
2	MgO (0.028%) W/V
3	$CaCl_2$ (0.016%) W/V
4	MgO (0.056%) W/V
5	$CaCl_2$ (0.032%) W/V
6	MgO (0.028%) + $CaCl_2$ (0.016%) W/V
7	MgO (0.056%) + $CaCl_2$ (0.016%) W/V
8	MgO (0.028%) + $CaCl_2$ (0.032%) W/V
9	MgO (0.056%) + $CaCl_2$ (0.032%) W/V

Harvest clusters of Flame grapes

The grape clusters were harvested at the mature stage in the final week of May during both the 2022 and 2023 seasons. At harvest, they exhibited a mild, sweet flavor with a crisp texture, characterized by plump, firm berries that were securely attached to the stems. Maturity was confirmed by achieving a Soluble solids content (S.S.C.) percentage of 14% or higher in berry juice. The clusters were then transported to the laboratory of the Agriculture Development Systems (ADS) project at the Faculty of Agriculture, Cairo University. Only clusters free from mechanical damage and visible deterioration were selected and standardized based on uniformity in size, color, and form. The standardized clusters were then randomly distributed into eight groups. At the harvest date, clusters were sampled from each replicate of every treatment to assess the average cluster weight (g), yield (kg/vine), and fruit quality. Both the physical and chemical characteristics of the berries were evaluated for each treatment during both seasons.

Berries characteristics:

Representative random samples of 12 cluster /treatment (3 cluster from each replicate) were picked at the harvesting stage for the following determination berries characteristics as a random sample of 100 berries per each replication was taken to determine

(Respiration Rate& Berry Firmness &. Berry Adherence Strength& Shattering Percentage& Soluble Solid Content (SSC Brix) & Total Titratable Acidity (TTA) & Maturity Index &Vitamin C (L-Ascorbic Acid & pH& Total sugars & Total Phenolic Content)

pH of berry juice: The pH of fruit juices was measured at 20 ◦ C using a pH meter (Jenwa3320, Bibby Scientific, Staffordshire, UK).

Market life

Treated grape clusters were carefully placed in four pre-labeled carton boxes (30 × 40 × 20 cm) for each treatment. Each box served a specific purpose: one for determining discarded fruit, another for assessing weight loss, and a third for evaluating fruit quality parameters every three days over a 12-day period. Sampling intervals included 0 days (at harvest), 3, 6, 9, and 12 days of market life. Each box contained 2 kg of fruit, with three replicates per treatment. The experiment was conducted twice, during the 2022 and 2023 seasons.

The boxes were randomly assigned to one of the treatment conditions and stored under simulated market conditions in refrigerators at 10 °C ± 1 and 90% relative humidity (RH) for a 12-day storage market period to simulate the display refrigerator in the supermarket as marketing life, in refrigerators. The refrigeration facilities were provided by the Agricultural Development Systems (ADS) project at the Faculty of Agriculture, Cairo University.

The market-life experiment was arranged in a completely randomized factorial design. Quality measurements, including the physicochemical properties of the fruit, were assessed to evaluate the impact of the treatments during storage.

Fruit Quality Assessments at market period

Discard Percentage: Grapes showing signs of decay or visual disorders were weighed. The percentage of discarded berries was calculated based on the total fruit weight using the following formula:

$$\text{Discarded \%} = \left(\frac{Weight\ of\ discarded\ berries\ (g)}{Initial\ weight\ (g)}\right) \times 100$$

Weight Loss Percentage: The weight loss percentage was determined by calculating the difference between the initial weight of the clusters and the weight recorded at each sampling time. The weight loss percentage was calculated using the following equation:

$$\text{Weight loss \%} = \left(\frac{Weight\ loss\ (g)}{Initial\ weight\ of\ clusters\ (g)}\right) \times 100$$

Respiration Rate: The respiration rate was measured by placing individual small clusters for each treatment in 2-liter jars at 20°C. The jars were sealed for 3 hours, and the O_2 and CO_2 levels in the headspace were measured using a syringe and injected into a Servomex Inst. Model 1450C Food Pack Gas Analyzer to determine the oxygen and carbon dioxide production. Respiration rate was calculated as ml CO_2/kg fruit/hr using the following formula:

$$\text{Respiration rate (ml } CO_2\text{ kg}^{-1}\text{hr}^{-1}) = \frac{CO_2\ concentration\ (\%)\ \times headspace\ air\ volume\ (L) \times 1000}{fruit\ weight\ (kg) \times incubation\ period\ (hr) \times 1000}$$

Respiration rate was measured initially at room temperature and every third day thereafter until the end of the market life (12 days)

Berry Firmness (g/cm²): Berry firmness was measured using a Shatilon instrument designed for grape firmness assessment. The average firmness of all berries was recorded in grams per square centimeter

Adherence Strength (g): The adherence strength of the grape berries was measured using a scale and force meter (Shatilon instrument). The force required to detach the berry from its pedicel was recorded in grams per square centimeter (g/cm²), representing the adherence strength between the berry and its pedicel.

Shattering Percentage: The shattering percentage was calculated based on the weight of shattered berries relative to the initial weight of the clusters. The shattering percentage was determined using the following formula:

$$\text{Shattering \%} = \left(\frac{Weight\ of\ shattered\ berries\ (g)}{Initial\ weight\ of\ clusters\ (g)}\right) \times 100$$

Maturity Index: The maturity index was calculated as the ratio of SSC to total acidity (SSC/TTA), providing a relative measure of fruit maturity.

Vitamin C (L-Ascorbic Acid) (mg/100 g juice): Vitamin C content was determined using the 2,5-dichlorophenol indophenol method.

Total Phenolic Content (mg/ 100 g F.W): Total phenols were quantified using the Folin-Ciocalteu method. A 0.5 g sample of grape tissue was extracted with 20 ml of 80% methanol. An aliquot (1 ml) of this extract was mixed with 1 ml of Folin-Ciocalteu reagent, followed by the addition of 4 ml of 20% sodium carbonate solution. The mixture was incubated in the dark for 90 minutes, after which the absorbance was measured at 725 nm. Gallic acid was used as the standard, and results are expressed as mg of gallic acid equivalents per 100 g of fresh weight (mg/100 g FW).

Statistical Analysis

The results of yield and cluster weight were performed in triplicate using a completely randomized design. Physiochemical parameter results were also performed in triplicate using a completely randomized factorial design. Data were analyzed using the Analysis of Variance (ANOVA) procedure of MSTAT-C software. When significant differences were detected, treatment means were compared by the Least Significant Difference (LSD) range test at the 5% level of probability for both the 2022 and 2023 seasons**.**

2 Results and discussion

Effect of pre-harvest magnesium and calcium pre harvest treatments on fruit quality parameters

1. Cluster Weight and Yield:

The data presented in Table 3 demonstrate that pre-harvest applications significantly influenced cluster weight and yield (kg per vine) in *Flame Seedless* grapevines. The highest significant increases in cluster weight and yield were observed in vines treated with a combined application of magnesium (Mg) and calcium (Ca) compared to the untreated control, which consistently recorded the lowest values across both growing seasons. From an economic perspective, the application of higher concentrations of Mg and Ca yielded superior results in terms of total yield. Specifically, treatments involving MgO at 0.056% combined with $CaCl_2$ at 0.032% and MgO at 0.028% combined with $CaCl_2$ at 0.032% performed best, followed by MgO at 0.056% combined with $CaCl_2$ at 0.016%, in descending order. These treatments resulted in a significant improvement in yield per vine during both seasons compared to untreated vines.

The observed increase in cluster weight and yield can be attributed to the physiological roles of calcium and magnesium in plant growth and development. Calcium is known to promote longitudinal growth and cell division in meristematic tissues, with a specific effect on cell elongation and differentiation [5]. This contributes to increased cell size, enhanced juice accumulation, and, consequently, greater cluster weight. Magnesium, on the other hand, plays a critical role in photosynthesis by facilitating the synthesis of chlorophyll molecules, which enhances carbohydrate production. The resulting carbohydrates improve the nutrient status of the vines, promoting vegetative growth and subsequently increasing cluster weight and yield [6].

The ratio of Mg to Ca has been shown to be a more reliable indicator of yield and quality responses than the individual levels of Mg or Ca. This synergistic effect was particularly pronounced when Mg and Ca were applied in combination, resulting in significant improvements in cluster weight and yield. These findings align with previous studies, which reported similar increases in cluster weight and yield through the use of Ca in superior grapes and combined applications of Ca, Mg, and Mo in Flame Seedless grapevines [4].

Table 3. Effect of magnesium and calcium pre-harvest treatments on Cluster Weight and Total yield of flame grape fruits during two seasons.

Treatments (T)	Clusters Weight		KG/Vine		Ton/Fed	
	2022	2023	2022	2023	2022	2023
Control	375.07	375.44	12.75	12.76	8.93	8.94
MgO (0.028%) W/V	382.74	397.48	13.01	13.51	9.11	9.46
$CaCl_2$ (0.016%) W/V	438.61	447.28	14.91	15.21	10.44	10.65
MgO (0.056%) W/V	397.46	427.41	13.51	14.53	9.46	10.17
$CaCl_2$ (0.032%) W/V	472.99	295.14	16.08	10.03	11.26	7.02
MgO (0.028%) + $CaCl_2$ (0.016%) W/V	467.17	456.81	15.88	15.53	11.12	10.87
MgO (0.056%) + $CaCl_2$ (0.016%) W/V	458.00	476.80	15.57	16.21	10.90	11.35

MgO (0.028%) + $CaCl_2$ (0.032%) W/V	497.40	527.96	16.91	17.95	11.84	12.57
MgO (0.056%) + $CaCl_2$ (0.032%) W/V	529.69	537.19	18.01	18.26	12.61	12.79
Mean	446.57	437.94	15.18	14.89	10.63	10.42
L.S.D at 0.05	**21.18**	**22.60**	**0.72**	**0.77**	**0.50**	**0.54**

2. pH of Berry Juice

High pH levels in grapes are often attributed to strong vine canopies, which facilitate excessive uptake of nitrogen and potassium. This nutrient imbalance, often exacerbated by optimal water availability, increases both grape and juice pH, ultimately compromising wine quality. Data presented in Table 4 demonstrate that fruit juice pH significantly decreased as the storage period progressed, reaching the lowest values at the end of the 12-day market period. Pre-harvest treatments combining magnesium (Mg) and calcium (Ca) resulted in slightly higher juice pH levels compared to the control. Among these treatments, MgO at 0.056% combined with $CaCl_2$ at 0.032% was the most effective, followed by MgO at 0.028% + $CaCl_2$ at 0.032%, and MgO at 0.028% + $CaCl_2$ at 0.016%, in descending order of efficacy. These combinations delayed the decline in juice pH during cold storage.

The untreated control consistently recorded the lowest pH values in both growing seasons. The interaction between pre-harvest treatments and storage periods revealed that the treatments were significantly more effective in maintaining pH levels during the 2022 and 2023 seasons. Control fruits exhibited a more rapid decline in pH during the market period, indicating a higher utilization of organic acids and elevated respiration rates compared to treated fruits. The combination of Mg and Ca had a pronounced effect on maintaining pH, likely due to their synergistic impact on vine nutrient uptake and fruit quality.

The role of juice pH is critical in grape processing, influencing both the fermentation process and the sensory characteristics of the final product. An ideal juice pH range is between 3.0 and 4.0. Control treatments often resulted in overripe grapes with juice pH levels exceeding 4.0, which can lead to oxidation and reduced juice quality. Thus, monitoring and managing pH before harvest is essential.

During ripening, juice pH increases due to the catabolism of organic acids, as these acids are utilized in respiration and converted into sugars. It is noted that during ripening, fruit filling predominantly occurs through concordance, where H^+ ions play a pivotal role in glucose and sucrose formation [7]. The concentration of H^+ ions at the vacuolar level decreases, leading to a gradual rise in pH. Calcium applications likely slow down this pH increase by reducing respiration rates and metabolic activity, thereby minimizing the oxidation of organic acids.

Similar findings showed that a 2% $CaCl_2$ application maintained higher pH values in fruits at the end of a 20-day storage period compared to untreated controls [8]. Additionally, magnesium's contribution to maintaining cell integrity and vitality in grape clusters protected against internal transformations, preserving fruit quality and extending the marketability of Flame Seedless grapes.

Table 4. Effect of magnesium and calcium pre-harvest treatments on ph. juice of flame grape fruits in 2022 and 2023 seasons**.**

Treatments (T)	2022	2023
Control	3.97	3.93
MgO (0.028%) W/V	3.73	3.70
$CaCl_2$ (0.016%) W/V	3.27	3.23

MgO (0.056%) W/V	3.47	3.43
$CaCl_2$ (0.032%) W/V	3.17	1.88
MgO (0.028%) + $CaCl_2$ (0.016%) W/V	3.17	3.13
MgO (0.056%) + $CaCl_2$ (0.016%) W/V	3.07	3.03
MgO (0.028%) + $CaCl_2$ (0.032%) W/V	3.03	2.97
MgO (0.056%) + $CaCl_2$ (0.032%) W/V	3.00	2.93
Mean	3.32	3.14
L.S.D at 0.05	**0.13**	**0.10**

3. Discard:

The data presented in Tables 5 and 6 indicate that all pre-harvest treatments significantly reduced fruit decay across all storage periods. The most effective treatment was the application of MgO at 0.056% combined with $CaCl_2$ at 0.032%, followed by the combination of MgO at 0.028% with $CaCl_2$ at 0.032%, and finally MgO at 0.056% combined with $CaCl_2$ at 0.016%, in descending order of efficacy. These treatments outperformed the untreated control, which exhibited the highest decay rates. Furthermore, the percentage of decayed fruits increased progressively with the extension of storage duration, consistent with previous observations.

The interaction between pre-harvest treatments and storage durations (3, 6, 9, and 12 days) revealed that the untreated control showed the highest decay percentage at 12 days of storage. In contrast, the treatment with MgO at 0.056% + $CaCl_2$ at 0.032% consistently recorded the lowest decay percentages during both seasons.

These findings suggest that pre-harvest foliar applications of Mg and Ca, particularly in combination, significantly enhanced the resistance of *Flame Seedless* grape clusters to fungal diseases and physiological disorders, thereby improving their marketability. The observed reduction in decay may be attributed to the role of calcium in enhancing fruit resistance to fungal infections, delaying tissue softening, and improving membrane integrity. Calcium application has been reported to strengthen cell wall and membrane structures, reducing physiological disorders and decay during storage and marketing.

Magnesium also contributed to lowering decay rates by improving the nutritional status of grapevines and the overall health of clusters. This enhanced the immune response of the clusters, making them more resistant to infections and fungal activity. These results highlight the synergistic effects of Mg and Ca when applied together, offering an effective strategy for maintaining fruit quality and extending the shelf life of *Flame Seedless* grapes.

Table 5. Effect of magnesium and calcium pre-harvest treatments on Discard % of flame grape fruits during 12 days market period storage at (10^0C – 90RH %) in 2022 season.

	Marketing Period days (P)					
Treatments (T)	**D0**	**D03**	**D06**	**D09**	**D12**	**Mean**
Control	0.00	2.33	6.67	10.67	12.67	6.47
MgO (0.028%) W/V	0.00	3.00	6.00	8.67	9.67	5.47
$CaCl_2$ (0.016%) W/V	0.00	1.67	4.67	7.67	10.33	4.87
MgO (0.056%) W/V	0.00	2.67	5.33	7.67	10.00	5.13
$CaCl_2$ (0.032%) W/V	0.00	2.00	4.67	7.00	5.67	3.87
MgO (0.028%) + $CaCl_2$ (0.016%) W/V	0.00	2.33	3.33	5.67	6.67	3.60
MgO (0.056%) + $CaCl_2$ (0.016%) W/V	0.00	1.67	3.67	4.33	5.67	3.07
MgO (0.028%) + $CaCl_2$ (0.032%) W/V	0.00	1.33	3.33	3.33	2.67	2.13

MgO (0.056%) + $CaCl_2$ (0.032%) W/V	0.00	0.67	2.33	2.00	3.00	1.60
Mean	0.00	1.96	4.44	6.33	7.37	
L.S.D at 0.05	**Treatments (T) 0.97**		**M. Periods (P) 0.72**		**Interactions (T x P) 1.86**	

Table 6. Effect of magnesium and calcium pre-harvest treatments on Discard % of flame grape fruits during 12 days market period storage at (10^0C – 90RH %) in 2023 season.

	Marketing Period days (P)					
Treatments (T)	**D0**	**D03**	**D06**	**D09**	**D12**	**Mean**
Control	0.00	2.33	7.67	10.33	11.33	6.33
MgO (0.028%) W/V	0.00	2.33	6.00	8.33	10.67	5.47
$CaCl_2$ (0.016%) W/V	0.00	1.67	5.00	8.33	9.00	4.80
MgO (0.056%) W/V	0.00	1.67	5.33	8.33	10.00	5.07
$CaCl_2$ (0.032%) W/V	0.00	1.67	4.67	6.00	6.33	3.f73
MgO (0.028%) + $CaCl_2$ (0.016%) W/V	0.00	1.00	4.00	6.33	7.33	3.73
MgO (0.056%) + $CaCl_2$ (0.016%) W/V	0.00	1.33	3.67	5.67	7.00	3.53
MgO (0.028%) + $CaCl_2$ (0.032%) W/V	0.00	1.00	2.67	5.00	4.67	2.67
MgO (0.056%) + $CaCl_2$ (0.032%) W/V	0.00	0.33	2.33	3.00	2.67	1.67
Mean	0.00	1.48	4.59	6.81	7.67	
L.S.D at 0.05	**Treatments (T) 0.55**		**M. Periods (P) 0.41**		**Interactions (T x P) 1.06**	

4. Weight loss:

The data presented in Tables 7 and 8 demonstrate a significant difference between the treatments and the control regarding their effects on weight loss in Flame Seedless grape fruits. The highest weight loss values were observed in the control fruits across both seasons, whereas the lowest weight loss percentages were recorded in fruits treated pre-harvest with magnesium oxide (MgO) at 0.056% combined with calcium chloride ($CaCl_2$) at 0.032%. This was followed by MgO at 0.028% + $CaCl_2$ at 0.032% and MgO at 0.056% + $CaCl_2$ at 0.032% in descending order of effectiveness. Additionally, weight loss significantly increased as the storage period advanced, with the highest weight loss occurring at the end of the storage period.

The interaction between pre-harvest treatments and storage duration revealed that fruits treated with MgO at 0.056% + $CaCl_2$ at 0.032% maintained significantly lower weight loss values across different market periods (3, 6, 9, and up to 12 days of storage), preserving fruit weight effectively until the end of storage.

The combined application of magnesium and calcium had a more pronounced effect in reducing weight loss compared to their individual applications. Calcium reduces respiration during cold storage, which minimizes transpiration and fresh mass loss. Similarly, calcium applications help maintain fruit mass under cold storage conditions. Furthermore, magnesium improves the nutritional status of grape clusters, mitigating weight loss and thereby extending the marketable storage period of Flame Seedless grape fruits.

Table 7. Effect of magnesium and calcium pre-harvest treatments on weight loss % of flame grape fruits during 12 days market period storage at (10^0C – 90RH %) in 2022 season.

	Marketing Period days (P)					
Treatments (T)	**D0**	**D03**	**D06**	**D09**	**D12**	**Mean**
Control	0.00	0.57	0.80	1.12	1.57	0.81
MgO (0.028%) W/V	0.00	0.51	0.71	0.99	1.39	0.72
$CaCl_2$ (0.016%) W/V	0.00	0.40	0.56	0.78	1.09	0.56
MgO (0.056%) W/V	0.00	0.48	0.67	0.93	1.31	0.68
$CaCl_2$ (0.032%) W/V	0.00	0.31	0.43	0.60	0.84	0.44
MgO (0.028%) + $CaCl_2$ (0.016%) W/V	0.00	0.43	0.60	0.84	1.18	0.61
MgO (0.056%) + $CaCl_2$ (0.016%) W/V	0.00	0.41	0.58	0.81	1.13	0.59
MgO (0.028%) + $CaCl_2$ (0.032%) W/V	0.00	0.27	0.38	0.54	0.75	0.39
MgO (0.056%) + $CaCl_2$ (0.032%) W/V	0.00	0.23	0.33	0.46	0.64	0.33
Mean	0.00	0.40	0.56	0.79	1.10	
L.S.D at 0.05	**Treatments (T) 0.022**		**M. Periods (P) 0.017**		**Interactions (T x P) 0.043**	

Table 8. Effect of magnesium and calcium pre-harvest treatments on weight loss % of flame grape fruits during 12 days market period storage at (10^0C – 90RH %) in 2023 season.

	Marketing Period days (P)					
Treatments (T)	**D0**	**D03**	**D06**	**D09**	**D12**	**Mean**
Control	0.00	0.63	0.88	1.24	1.73	0.90
MgO (0.028%) W/V	0.00	0.53	0.78	1.09	1.55	0.79
$CaCl_2$ (0.016%) W/V	0.00	0.41	0.57	0.80	1.13	0.58
MgO (0.056%) W/V	0.00	0.52	0.73	1.03	1.44	0.74
$CaCl_2$ (0.032%) W/V	0.00	0.28	0.39	0.54	0.76	0.39
MgO (0.028%) + $CaCl_2$ (0.016%) W/V	0.00	0.47	0.66	0.93	1.30	0.67
MgO (0.056%) + $CaCl_2$ (0.016%) W/V	0.00	0.45	0.64	0.89	1.25	0.65
MgO (0.028%) + $CaCl_2$ (0.032%) W/V	0.00	0.25	0.34	0.48	0.68	0.35
MgO (0.056%) + $CaCl_2$ (0.032%) W/V	0.00	0.21	0.29	0.41	0.58	0.30
Mean	0.00	0.42	0.59	0.82	1.16	
L.S.D at 0.05	**Treatments (T) 0.022**		**M. Periods (P) 0.017**		**Interactions (T x P) 0.043**	

5. Respiration Rate

Respiration rate, a key indicator of metabolic activity, was evaluated in both treated and untreated "Flame Seedless" grape clusters. Data presented in Tables 9 and 10 indicate an initially elevated respiration rate at harvest, likely due to the field temperature conditions during fruit collection. However, respiration rates decreased significantly during the first week of cold storage at 10°C, as the lower temperature suppressed metabolic activity. This reduction in respiration rates was more pronounced in treated clusters and continued until the end of the market storage period during both seasons of investigation.

By the end of the market period, pre-harvest combination treatments—particularly MgO at 0.056% combined with $CaCl_2$ at 0.032% and MgO at 0.028% combined with $CaCl_2$ at 0.032%—had a significant effect in reducing respiration rates in "Flame Seedless" grapes. In contrast, untreated control fruits exhibited the highest respiration rates, particularly after 12 days of storage. The combined application of Mg and Ca was more effective than individual treatments, highlighting their synergistic impact on reducing respiration.

Interaction data further confirmed that MgO at 0.056% combined with $CaCl_2$ at 0.032% consistently achieved the lowest respiration rates across all market storage periods. A reduced respiration rate is beneficial as it retards fruit softening and slows down compositional changes, thereby preserving fruit quality during storage.

These findings align with prior research, which demonstrated the role of calcium in lowering respiration rates during cold storage. For instance, known is a similar effect of calcium in reducing respiration rates during 8 weeks of storage in superior grapes. The reduced metabolic activity associated with pre-harvest Mg and Ca treatments underscores their importance in extending the postharvest quality and marketability of "Flame Seedless" grapes.

Table 9. Effect of magnesium and calcium pre-harvest treatments on Respiration Rate of flame grape fruits during 12 days market period storage at (10^0C – 90RH %) in 2022 season.

	Marketing Period days (P)					
Treatments (T)	**D0**	**D03**	**D06**	**D09**	**D12**	**Mean**
Control	20.89	5.48	5.66	5.84	6.04	8.78
MgO (0.028%) W/V	20.25	5.36	5.53	5.72	5.91	8.55
$CaCl_2$ (0.016%) W/V	19.70	5.21	5.38	5.56	5.74	8.32
MgO (0.056%) W/V	20.04	5.29	5.46	5.64	5.83	8.45
$CaCl_2$ (0.032%) W/V	18.94	4.99	5.15	5.32	5.50	7.98
MgO (0.028%) + $CaCl_2$ (0.016%) W/V	19.68	5.18	5.35	5.53	5.71	8.29
MgO (0.056%) + $CaCl_2$ (0.016%) W/V	19.76	5.20	5.37	5.55	5.73	8.32
MgO (0.028%) + $CaCl_2$ (0.032%) W/V	18.96	4.99	5.15	5.32	5.50	7.98
MgO (0.056%) + $CaCl_2$ (0.032%) W/V	18.70	4.92	5.08	5.25	5.42	7.87
Mean	19.66	5.18	5.35	5.53	5.71	
L.S.D at 0.05	**Treatments (T) 0.028**		**M. Periods (P) 0.021**		**Interactions (T x P) 0.054**	

Table 10. Effect of magnesium and calcium pre-harvest treatments on Respiration Rate of flame grape fruits during 12 days market period storage at (10^0C – 90RH %) in 2023 season.

	Marketing Period days (P)					
Treatments (T)	**D0**	**D03**	**D06**	**D09**	**D12**	**Mean**
Control	21.01	5.53	5.72	5.92	6.13	8.86
MgO (0.028%) W/V	20.56	5.41	5.60	5.80	6.00	8.67
$CaCl_2$ (0.016%) W/V	19.73	5.19	5.38	5.56	5.76	8.32
MgO (0.056%) W/V	19.90	5.24	5.42	5.61	5.81	8.39
$CaCl_2$ (0.032%) W/V	18.75	4.94	5.11	5.29	5.47	7.91
MgO (0.028%) + $CaCl_2$ (0.016%) W/V	19.48	5.13	5.31	5.49	5.68	8.22
MgO (0.056%) + $CaCl_2$ (0.016%) W/V	19.57	5.15	5.33	5.52	5.71	8.25
MgO (0.028%) + $CaCl_2$ (0.032%) W/V	18.77	4.94	5.11	5.29	5.48	7.92
MgO (0.056%) + $CaCl_2$ (0.032%) W/V	18.51	4.87	5.04	5.22	5.40	7.81
Mean	19.59	5.15	5.34	5.52	5.72	
L.S.D at 0.05	**Treatments (T) 0.053**		**M. Periods (P) 0.040**		**Interactions (T x P) 0.102**	

6. Fruit Firmness

Fruit firmness is a key quality parameter in fruit marketing and storage. Data presented in Tables 11 and 12 indicate that all pre-harvest treatments significantly improved fruit firmness, whereas the untreated control exhibited the highest rate of fruit softening. Among the treatments, the combination of MgO at 0.056% with $CaCl_2$ at 0.032% retained the highest fruit firmness, followed by MgO at 0.028% with $CaCl_2$ at 0.032%, and then MgO at 0.028% with $CaCl_2$ at 0.016%. These treatments consistently maintained maximum fruit firmness throughout the market storage period across both growing seasons, while the control treatment recorded the lowest firmness values.

Fruit firmness decreased gradually and significantly over the storage period in all treatments. However, interaction data between pre-harvest treatments and market storage periods showed that the MgO at 0.056% + $CaCl_2$ at 0.032% treatment significantly improved firmness at all market storage intervals. The observed reduction in respiration rates in treated fruits likely contributed to delayed softening and slower compositional changes, further enhancing fruit firmness.

The superior firmness in treated fruits may be attributed to the synergistic effects of calcium and magnesium. Calcium application, in particular, delays fruit softening by inhibiting cell wall-degrading enzymes, including polygalacturonase and pectin methyl esterase. Additionally, calcium binds to cellular polymers, preventing cell collapse and disintegration. Magnesium and calcium cooperatively maintain cell wall integrity and tissue strength, contributing to an organized cell wall structure and stronger cell-to-cell adhesion. This results in firmer berries compared to the control, thereby extending the market life of the fruit.

Calcium and magnesium strongly bond with pectin in the cell wall, stabilizing its structure and maintaining fruit firmness [9]. These findings are consistent with previous studies, which reported that calcium application increased firmness during cold storage of grapes [10].

Table 11. Effect of magnesium and calcium pre-harvest treatments on firmness of flame grape fruits during 12 days market period storage at (10^0C – 90RH %) in 2022 season.

	Marketing Period days (P)					
Treatments (T)	**D0**	**D03**	**D06**	**D09**	**D12**	**Mean**
Control	336.67	303.00	272.70	245.43	220.89	275.74
MgO (0.028%) W/V	390.00	351.00	315.90	284.31	255.88	319.42
$CaCl_2$ (0.016%) W/V	532.00	478.80	430.92	387.83	349.05	435.72
MgO (0.056%) W/V	420.00	378.00	340.20	306.18	275.56	343.99
$CaCl_2$ (0.032%) W/V	586.33	527.70	474.93	427.44	384.69	480.22
MgO (0.028%) + $CaCl_2$ (0.016%) W/V	525.67	473.10	425.79	383.21	344.89	430.53
MgO (0.056%) + $CaCl_2$ (0.016%) W/V	549.00	494.10	444.69	400.22	360.20	449.64
MgO (0.028%) + $CaCl_2$ (0.032%) W/V	595.67	536.10	482.49	434.24	390.82	487.86
MgO (0.056%) + $CaCl_2$ (0.032%) W/V	633.00	569.70	512.73	461.46	415.31	518.44
Mean	507.59	456.83	411.15	370.04	333.03	
L.S.D at 0.05	**Treatments (T) 5.89**		**M. Periods (P) 4.39**		**Interactions (T x P) 11.28**	

Table 12. Effect of magnesium and calcium pre-harvest treatments on firmness of flame grape fruits during 12 days market period storage at (10^0C – 90RH %) in 2023 season.

	Marketing Period days (P)					
Treatments (T)	**D0**	**D03**	**D06**	**D09**	**D12**	**Mean**
Control	370.33	333.30	299.97	269.97	242.98	303.31
MgO (0.028%) W/V	429.00	386.10	347.49	312.74	281.47	351.36
$CaCl_2$ (0.016%) W/V	585.20	526.68	474.01	426.61	383.95	479.29
MgO (0.056%) W/V	462.00	415.80	374.22	336.80	303.12	378.39
$CaCl_2$ (0.032%) W/V	644.97	580.47	522.42	470.18	423.16	528.24
MgO (0.028%) + $CaCl_2$ (0.016%) W/V	578.23	520.41	468.37	421.53	379.38	473.58
MgO (0.056%) + $CaCl_2$ (0.016%) W/V	603.90	543.51	489.16	440.24	396.22	494.61
MgO (0.028%) + $CaCl_2$ (0.032%) W/V	655.23	589.71	530.74	477.67	429.90	536.65
MgO (0.056%) + $CaCl_2$ (0.032%) W/V	696.30	626.67	564.00	507.60	456.84	570.28
Mean	558.35	502.52	452.27	407.04	366.33	
L.S.D at 0.05	**Treatments (T) 6.48**		**M. Periods (P) 4.83**		**Interactions (T x P) 12.41**	

7. Adherence Strength

Berry adherence strength of *Flame Seedless* grape clusters decreased progressively during the cold storage market period at 10°C and 90–95% relative humidity, as shown in Tables 13 and 14. Among the treatments, MgO at 0.056% combined with $CaCl_2$ at 0.032% resulted in the highest significant berry adherence strength, followed by MgO at 0.028% + $CaCl_2$ at 0.032%, and finally MgO at 0.028% + $CaCl_2$ at 0.016%. These treatments consistently outperformed the untreated control during both growing seasons.

Analysis of the interaction between pre-harvest treatments and sampling periods revealed that MgO at 0.056% + $CaCl_2$ at 0.032% consistently recorded the highest adherence strength across different storage intervals. This indicates the pronounced effect of combining calcium and magnesium on berry adherence strength during the storage period.

Calcium plays a vital role in enhancing berry adherence strength by combining with pectic acids in the cell wall to form calcium pectate, which constitutes the structural framework of the cell wall. This structure prevents the disintegration of the gel layer within the cell wall, thereby maintaining the structural integrity of the fruit [11]. Previous studies have also demonstrated that calcium application markedly increases berry adherence strength during cold storage.

Magnesium complements calcium by serving as an activator for several enzymes involved in carbohydrate metabolism, which significantly reduces berry stem necrosis in grape clusters [12]. Furthermore, magnesium enhances the vitality and integrity of grape clusters by contributing to the structural organization at the attachment zone. The synergistic action of magnesium and calcium strengthens the cell layers at the berry attachment point, maintaining tensile strength and extending the market life of the fruit.

These findings highlight the effectiveness of pre-harvest Mg and Ca applications in improving berry adherence strength, thus contributing to the preservation of fruit quality and extending the storage and marketability period of *Flame Seedless* grapes.

Table 13. Effect of magnesium and calcium pre-harvest treatments on Adherence Strength of flame grape fruits during 12 days market period storage at (10^0C – 90RH %) in 2022 season.

	Marketing Period days (P)					
Treatments (T)	**D0**	**D03**	**D06**	**D09**	**D12**	**Mean**
Control	243.24	226.21	210.38	195.65	181.96	211.49
MgO (0.028%) W/V	281.78	262.05	243.71	226.65	210.78	244.99
$CaCl_2$ (0.016%) W/V	384.37	357.46	332.44	309.17	287.53	334.20
MgO (0.056%) W/V	303.45	282.21	262.45	244.08	227.00	263.84
$CaCl_2$ (0.032%) W/V	423.63	393.97	366.39	340.75	316.89	368.33
MgO (0.028%) + $CaCl_2$ (0.016%) W/V	379.79	353.21	328.48	305.49	284.11	330.22
MgO (0.056%) + $CaCl_2$ (0.016%) W/V	396.65	368.89	343.06	319.05	296.72	344.87
MgO (0.028%) + $CaCl_2$ (0.032%) W/V	430.37	400.24	372.23	346.17	321.94	374.19
MgO (0.056%) + $CaCl_2$ (0.032%) W/V	457.34	425.33	395.56	367.87	342.12	397.64
Mean	366.74	341.06	317.19	294.99	274.34	
L.S.D at 0.05	**Treatments (T) 4.496**		**M. Periods (P) 3.351**		**Interactions (T x P) 8.608**	

Table 14. Effect of magnesium and calcium pre-harvest treatments on Adherence Strength of flame grape fruits during 12 days market period storage at (10^0C – 90RH %) in 2023 season.

	Marketing Period days (P)					
Treatments (T)	**D0**	**D03**	**D06**	**D09**	**D12**	**Mean**
Control	279.73	260.15	241.94	225.00	209.25	243.21
MgO (0.028%) W/V	324.04	301.36	280.26	260.64	242.40	281.74
$CaCl_2$ (0.016%) W/V	442.03	411.08	382.31	355.55	330.66	384.32
MgO (0.056%) W/V	348.97	324.54	301.82	280.69	261.05	303.41
$CaCl_2$ (0.032%) W/V	487.17	453.07	421.35	391.86	364.43	423.58
MgO (0.028%) + $CaCl_2$ (0.016%) W/V	436.76	406.19	377.76	351.31	326.72	379.75
MgO (0.056%) + $CaCl_2$ (0.016%) W/V	456.15	424.22	394.52	366.91	341.22	396.61
MgO (0.028%) + $CaCl_2$ (0.032%) W/V	494.92	460.28	428.06	398.10	370.23	430.32
MgO (0.056%) + $CaCl_2$ (0.032%) W/V	525.94	489.13	454.89	423.05	393.43	457.29
Mean	421.75	392.22	364.77	339.23	315.49	
L.S.D at 0.05	**Treatments (T)** 5.17		**M. Periods (P)** 3.85		**Interactions (T x P)** 9.90	

8. Shattering Percentage

The effect of pre-harvest treatments on the shattering percentage of *Flame Seedless* grapes was evaluated during the storage market period. Data presented in Tables 15 and 16 indicate that shattering percentage increased progressively with storage time, reaching its highest values at the end of the market period. However, all pre-harvest treatments significantly reduced shattering, with the combination of MgO at 0.056% and $CaCl_2$ at 0.032% showing the lowest values compared to the untreated control during both seasons.

The synergistic effect of calcium and magnesium was particularly pronounced, with MgO at 0.056% + $CaCl_2$ at 0.032% consistently achieving the lowest shattering percentage across all market storage intervals. Interaction data confirmed that this combination maintained the lowest shattering rates throughout the study.

The application of calcium increased its concentration in the berry, primarily within the cell wall fraction of the skin. Calcium ions (Ca^{2+}) enhance cell wall stability by chelating the free carboxylic groups of galacturonic acid units [13, 14]. At the berry-pedicel junction, calcium forms strong bonds between cell walls, significantly strengthening the attachment zone. This structural reinforcement acts as a "glue" holding cells together, reducing berry detachment and maintaining cluster integrity. These findings align with previous studies, which demonstrated that calcium application effectively reduced shattering during cold storage in superior grapes and in 'Cheongsoo' grapes.

Magnesium also plays a crucial role in reducing shattering by supporting the vascular system that connects berries to the cluster stem. Adequate magnesium levels maintain proper vascular function, minimizing berry drop and preserving cluster integrity. Magnesium further enhances cell vitality and structural integrity, contributing to improved fruit quality and extended marketability of *Flame Seedless* grapes.

Calcium and magnesium work together to maintain berry attachment by contributing to cell wall development. Calcium forms calcium pectin complexes, strengthening cell walls and increasing resistance at the abscission zone. Concurrently, magnesium supports enzymes responsible for cell wall synthesis, further reducing berry drop. This cooperative action between calcium and magnesium effectively minimizes shattering during storage and extends the market life of *Flame Seedless* grapes.

Table 15. Effect of magnesium and calcium pre-harvest treatments on Shattering % of flame grape fruits during 12 days market period storage at (10^0C – 90RH %) in 2022 season.

	Marketing Period days (P)					
Treatments (T)	**D0**	**D03**	**D06**	**D09**	**D12**	**Mean**
Control	0.00	4.67	8.33	12.00	15.00	8.00
MgO (0.028%) W/V	0.00	2.33	6.67	11.00	15.33	7.07
$CaCl_2$ (0.016%) W/V	0.00	1.67	5.00	8.33	11.67	5.33
MgO (0.056%) W/V	0.00	1.67	5.33	9.00	12.67	5.73
$CaCl_2$ (0.032%) W/V	0.00	1.67	4.67	7.67	10.67	4.93
MgO (0.028%) + $CaCl_2$ (0.016%) W/V	0.00	1.33	4.00	6.33	8.67	4.07
MgO (0.056%) + $CaCl_2$ (0.016%) W/V	0.00	1.67	3.67	5.67	7.67	3.73
MgO (0.028%) + $CaCl_2$ (0.032%) W/V	0.00	1.67	3.33	5.00	6.67	3.33
MgO (0.056%) + $CaCl_2$ (0.032%) W/V	0.00	1.67	2.67	4.00	4.67	2.60
Mean	0.00	2.04	4.85	7.67	10.33	
L.S.D at 0.05	**Treatments (T) 0.73**		**M. Periods (P) 0.54**		**Interactions (T x P) 1.39**	

Table 16. Effect of magnesium and calcium pre-harvest treatments on Shattering % of flame grape fruits during 12 days market period storage at (10^0C – 90RH %) in 2023 season.

	Marketing Period days (P)					
Treatments (T)	**D0**	**D03**	**D06**	**D09**	**D12**	**Mean**
Control	0.00	3.67	9.00	13.00	14.33	8.00
MgO (0.028%) W/V	0.00	3.67	8.00	8.33	11.00	6.20
$CaCl_2$ (0.016%) W/V	0.00	2.33	5.67	7.00	9.33	4.87
MgO (0.056%) W/V	0.00	3.00	5.00	7.00	10.33	5.07
$CaCl_2$ (0.032%) W/V	0.00	2.33	4.67	7.00	9.33	4.67
MgO (0.028%) + $CaCl_2$ (0.016%) W/V	0.00	2.33	4.33	5.67	7.00	3.87
MgO (0.056%) + $CaCl_2$ (0.016%) W/V	0.00	1.67	3.67	5.67	7.67	3.73
MgO (0.028%) + $CaCl_2$ (0.032%) W/V	0.00	1.33	3.33	5.00	6.67	3.27
MgO (0.056%) + $CaCl_2$ (0.032%) W/V	0.00	1.00	2.67	4.00	5.00	2.53
Mean	0.00	2.37	5.15	6.96	8.96	
L.S.D at 0.05	**Treatments (T) 0.89**		**M. Periods (P) 0.664**		**Interactions (T x P) 1.70**	

9. Soluble Solids Content (S.S.C.)

Soluble solids content (S.S.C.) is a critical factor influencing fruit flavor, which is one of the most impactful quality attributes in the market. The results presented in Tables 17 and 18 indicate that pre-harvest treatments significantly influenced S.S.C. levels in *Flame Seedless* grapevines. The highest levels of S.S.C. were recorded at harvest in fruits treated with MgO at 0.056% combined with $CaCl_2$ at 0.032% during both seasons. S.S.C. increased progressively during storage, reaching maximum values at the end of the 12-day market storage period. This increase is likely attributed to the loss of dry matter through respiration and metabolic activity, as well as moisture loss through transpiration.

Despite the general trend of increasing S.S.C. during storage, fruits treated with pre-harvest MgO at 0.056% + $CaCl_2$ at 0.032% exhibited significantly lower increases in S.S.C. compared to untreated control fruits. Interaction data further revealed that fruits treated with MgO at 0.056% + $CaCl_2$ at 0.032% maintained the lowest increase in S.S.C. during the 12-day storage period, followed by treatments with MgO at 0.028% + $CaCl_2$ at 0.032%, MgO at 0.028% + $CaCl_2$ at 0.032%, and MgO at 0.028% + $CaCl_2$ at 0.016%, in descending order.

The combined application of magnesium and calcium had a pronounced effect on slowing the increase in S.S.C. This effect is likely due to reduced respiration rates, which minimize water loss from the fruit surface and delay deterioration processes. Calcium application may also reduce the concentration of soluble solids in fruit during storage, as observed in similar studies on superior grapes. Magnesium, on the other hand, enhances cell integrity and cluster vitality, protecting against internal transformations and preserving dissolved solids. This preservation effect contributes to maintaining fruit quality and extending the marketability of *Flame Seedless* grapes.

Table 17. Effect of magnesium and calcium pre-harvest treatments on Soluble Solids Content of flame grape fruits during 12 days market period storage at (10^0C – 90RH %) in 2022 season.

	Marketing Period days (P)					
Treatments (T)	**D0**	**D03**	**D06**	**D09**	**D12**	**Mean**
Control	15.60	16.00	16.10	16.14	16.24	16.02
MgO (0.028%) W/V	15.60	16.10	16.11	16.43	16.65	16.18
$CaCl_2$ (0.016%) W/V	15.60	16.07	16.20	16.43	16.53	16.17
MgO (0.056%) W/V	15.82	16.17	16.22	16.81	16.91	16.38
$CaCl_2$ (0.032%) W/V	15.67	16.10	16.29	16.74	16.84	16.33
MgO (0.028%) + $CaCl_2$ (0.016%) W/V	15.77	16.21	16.51	16.72	16.89	16.42
MgO (0.056%) + $CaCl_2$ (0.016%) W/V	15.77	16.17	16.55	16.90	17.10	16.50
MgO (0.028%) + $CaCl_2$ (0.032%) W/V	15.67	16.11	16.54	16.80	16.93	16.41
MgO (0.056%) + $CaCl_2$ (0.032%) W/V	15.77	16.11	16.46	17.07	17.33	16.55
Mean	15.69	16.11	16.33	16.67	16.83	
L.S.D at 0.05	**Treatments (T)** 0.09		**M. Periods (P)** 0.07		**Interactions (T x P)** 0.18	

Table 18. Effect of magnesium and calcium pre-harvest treatments on Soluble Solids Content of flame grape fruits during 12 days market period storage at (10^0C – 90RH %) in 2023 season.

	Marketing Period days (P)					
Treatments (T)	**D0**	**D03**	**D06**	**D09**	**D12**	**Mean**
Control	15.60	15.50	15.60	15.64	15.74	15.62
MgO (0.028%) W/V	15.60	15.60	15.61	15.93	16.15	15.78
$CaCl_2$ (0.016%) W/V	15.60	15.57	15.70	15.93	16.03	15.77
MgO (0.056%) W/V	15.82	15.67	15.72	16.31	16.41	15.98
$CaCl_2$ (0.032%) W/V	15.67	15.60	15.79	16.24	16.34	15.93
MgO (0.028%) + $CaCl_2$ (0.016%) W/V	15.77	15.71	16.01	16.22	16.39	16.02

MgO (0.056%) + $CaCl_2$ (0.016%) W/V	15.77	15.67	16.05	16.40	16.60	16.10
MgO (0.028%) + $CaCl_2$ (0.032%) W/V	15.67	15.61	16.04	16.30	16.43	16.01
MgO (0.056%) + $CaCl_2$ (0.032%) W/V	15.77	15.61	15.96	16.57	16.83	16.15
Mean	15.69	15.61	15.83	16.17	16.33	
L.S.D at 0.05	**Treatments (T) 0.09**		**M. Periods (P) 0.07**		**Interactions (T x P) 0.18**	

10. Total Titratable Acidity (TTA)

The flavor of fruit during storage is closely associated with its organic acid content. Data presented in Tables 18 and 19 demonstrate a significant decrease in fruit acidity as the storage period progressed, with the lowest acidity values recorded at the end of the 12-day market storage period. This trend aligns a decline in fruit acidity during storage.

Pre-harvest combined treatments, particularly MgO at 0.056% + $CaCl_2$ at 0.032%, followed by MgO at 0.028% + $CaCl_2$ at 0.032%, and MgO at 0.028% + $CaCl_2$ at 0.016%, effectively delayed the decrease in total acidity concentrations during the cold storage market period. In contrast, control fruits exhibited the lowest acidity values across both seasons, highlighting the superior efficacy of pre-harvest treatments in preserving fruit acidity.

The combined effects of storage duration and pre-harvest treatments on total acidity further revealed that the treatments significantly delayed the decline in titratable acidity during the 2022 and 2023 seasons. The faster decrease in total acidity observed in control fruits suggests higher organic acid metabolism and a higher respiration rate in untreated fruits.

Pre-harvest combined treatments with magnesium and calcium effectively slowed the decline in acidity during storage. The additional calcium reduced the respiration rate, delaying the metabolic changes of organic acids and maintaining titratable acidity in grape clusters. Magnesium contributed to maintaining cell integrity and delaying organic transformations, thereby preserving fruit quality and extending the market life of Flame grapes.

The foliar application of Mg and Ca thus not only reduced the rate of acidity decline but also enhanced the marketing potential of Flame Seedless grape clusters over extended storage periods.

Table 19. Effect of magnesium and calcium pre-harvest treatments on Total acidity of flame grape fruits during 12 days market period storage at (10^0C – 90RH %) in 2022 season.

	Marketing Period days (P)					
Treatments (T)	**D0**	**D03**	**D06**	**D09**	**D12**	**Mean**
Control	0.64	0.54	0.49	0.45	0.32	0.49
MgO (0.028%) W/V	0.68	0.58	0.50	0.45	0.34	0.51
$CaCl_2$ (0.016%) W/V	0.71	0.62	0.55	0.54	0.41	0.57
MgO (0.056%) W/V	0.65	0.58	0.57	0.48	0.38	0.53
$CaCl_2$ (0.032%) W/V	0.87	0.75	0.66	0.61	0.59	0.70
MgO (0.028%) + $CaCl_2$ (0.016%) W/V	0.71	0.59	0.63	0.59	0.45	0.59
MgO (0.056%) + $CaCl_2$ (0.016%) W/V	0.75	0.64	0.66	0.62	0.49	0.63
MgO (0.028%) + $CaCl_2$ (0.032%) W/V	0.85	0.72	0.71	0.63	0.59	0.70
MgO (0.056%) + $CaCl_2$ (0.032%) W/V	0.91	0.83	0.75	0.69	0.60	0.76
Mean	0.75	0.65	0.61	0.56	0.46	

L.S.D at 0.05	**Treatments (T) 0.015**	**M. Periods (P) 0.011**	**Interactions (T x P) 0.028**

Table 20. Effect of magnesium and calcium pre-harvest treatments on Total acidity of flame grape fruits during 12 days market period storage at (10^0C – 90RH %) in 2023 season.

	Marketing Period days (P)					
Treatments (T)	**D0**	**D03**	**D06**	**D09**	**D12**	**Mean**
Control	0.66	0.56	0.51	0.46	0.34	0.50
MgO (0.028%) W/V	0.70	0.60	0.52	0.46	0.35	0.53
$CaCl_2$ (0.016%) W/V	0.73	0.64	0.58	0.55	0.43	0.59
MgO (0.056%) W/V	0.67	0.60	0.59	0.49	0.40	0.55
$CaCl_2$ (0.032%) W/V	0.89	0.78	0.68	0.63	0.62	0.72
MgO (0.028%) + $CaCl_2$ (0.016%) W/V	0.73	0.62	0.65	0.60	0.48	0.62
MgO (0.056%) + $CaCl_2$ (0.016%) W/V	0.77	0.66	0.69	0.64	0.51	0.65
MgO (0.028%) + $CaCl_2$ (0.032%) W/V	0.87	0.75	0.74	0.65	0.62	0.73
MgO (0.056%) + $CaCl_2$ (0.032%) W/V	0.93	0.86	0.78	0.71	0.63	0.78
Mean	0.77	0.68	0.64	0.58	0.49	
L.S.D at 0.05	**Treatments (T)** 0.015		**M. Periods (P)** 0.011		**Interactions (T x P)** 0.029	

11. Maturity index (SSC/ acid ratio)

Data presented in Tables 20 and 21 indicate that the maturity index (SSC/acid ratio) in fruit juice was significantly lower in all pre-harvest treatments at harvest and throughout the cold storage market period compared to the control. In contrast, the SSC/acid ratio increased markedly in the control fruits during both harvest and storage periods, primarily due to an increase in total soluble solids (SSC) and a reduction in total juice acidity. The effect of calcium (Ca) and magnesium (Mg) was more pronounced when applied in combination, particularly with pre-harvest treatments such as MgO at 0.056% + $CaCl_2$ at 0.032%, followed by MgO at 0.028% + $CaCl_2$ at 0.032%, and MgO at 0.028% + $CaCl_2$ at 0.016%. These treatments effectively delayed the increase in the SSC/acid ratio during the marketing period, attributed to their ability to slow the increase in SSC and maintain higher acidity levels during both seasons.

The interaction effects revealed that holding Flame Seedless grape clusters in cold storage for 12 days resulted in a significantly lower increase in the SSC/acid ratio, particularly in fruits treated pre-harvest with MgO at 0.056% + $CaCl_2$ at 0.032% during both seasons.

The combined application of Mg and Ca in pre-harvest treatments also influenced fruit maturity at harvest. These treatments reduced the respiration rate, decreased the utilization of organic acids, and slowed water loss, collectively leading to a minimal increase in the SSC/TTA ratio during the storage period. This highlights the effectiveness of these treatments in maintaining fruit quality and extending marketability.

These findings demonstrated that calcium applications maintained high total acidity and generated low total soluble solids (SSC) values in Superior grapes during cold storage, thereby preserving fruit quality. Magnesium further enhanced cell integrity and protected against internal biochemical transformations, contributing to the extension of the market period for Flame grapes.

Table 21. Effect of magnesium and calcium pre-harvest treatments on Maturity index of flame grape fruits during 12 days market period storage at (10^0C – 90RH %) in 2022 season.

	Marketing Period days (P)					
Treatments (T)	**D0**	**D03**	**D06**	**D09**	**D12**	**Mean**
Control	24.50	29.57	33.12	36.28	50.37	34.77
MgO (0.028%) W/V	22.94	27.86	32.22	36.55	49.91	33.90
$CaCl_2$ (0.016%) W/V	21.97	26.13	29.41	30.69	40.03	29.65
MgO (0.056%) W/V	24.21	27.88	28.63	35.02	44.92	32.13
$CaCl_2$ (0.032%) W/V	18.08	21.38	24.81	27.47	28.39	24.03
MgO (0.028%) + $CaCl_2$ (0.016%) W/V	22.22	27.37	26.38	28.54	37.33	28.37
MgO (0.056%) + $CaCl_2$ (0.016%) W/V	21.02	25.36	25.16	27.52	34.94	26.80
MgO (0.028%) + $CaCl_2$ (0.032%) W/V	18.50	22.38	23.19	26.81	28.71	23.92
MgO (0.056%) + $CaCl_2$ (0.032%) W/V	17.39	19.49	21.85		28.74	22.47
Mean	21.21	25.27	27.20	30.42	38.15	
L.S.D at 0.05	**Treatments (T)** 1.05		**M. Periods (P) 0.78**		**Interactions (T x P) 2.01**	

Table 22. Effect of magnesium and calcium pre-harvest treatments on Maturity index of flame grape fruits during 12 days market period storage at (10^0C – 90RH %) in 2023 season.

	Marketing Period days (P)					
Treatments (T)	**D0**	**D03**	**D06**	**D09**	**D12**	**Mean**
Control	23.79	27.54	30.86	34.13	46.49	32.56
MgO (0.028%) W/V	22.28	25.96	30.02	34.40	46.10	31.75
$CaCl_2$ (0.016%) W/V	21.33	24.34	27.41	28.89	36.97	27.79
MgO (0.056%) W/V	23.51	25.98	26.68	32.99	41.52	30.13
$CaCl_2$ (0.032%) W/V	17.56	19.92	23.12	25.88	26.24	22.54
MgO (0.028%) + $CaCl_2$ (0.016%) W/V	21.57	25.51	24.60	26.88	34.50	26.61
MgO (0.056%) + $CaCl_2$ (0.016%) W/V	20.41	23.63	23.46	25.93	32.30	25.15
MgO (0.028%) + $CaCl_2$ (0.032%) W/V	17.97	20.85	21.63	25.26	26.53	22.45
MgO (0.056%) + $CaCl_2$ (0.032%) W/V	16.88	18.16	20.38	23.43	26.58	21.09
Mean	20.59	23.54	25.35	28.64	35.25	
L.S.D at 0.05	**Treatments (T)** 0.97		**M. Periods (P)** 0.73		**Interactions (T x P)** 1.87	

12. Vitamin C (L-Ascorbic acid)

Vitamin C, comprising as ascorbic acid and dehydroascorbic acid, is a critical nutritional component in fresh fruits. Data presented in Tables 22 and 23 show that pre-harvest treatments significantly influenced Vitamin C content in Flame Seedless grapes. The highest Vitamin C values were observed in fruits treated with MgO at 0.056% + $CaCl_2$ at 0.032%, followed by MgO at 0.028% + $CaCl_2$ at 0.032%, and MgO at 0.028% + $CaCl_2$ at 0.016% in descending order. In contrast, the control treatment consistently recorded the lowest Vitamin C content across both seasons.

During the storage period, Vitamin C content decreased gradually and significantly, reaching its lowest level at the end of the 12-day market period compared to levels observed at harvest. This decline is likely due to the activity of oxidizing enzymes such as ascorbic acid oxidase, peroxidase, catalase, and polyphenol oxidase, which degrade ascorbic acid during storage. Despite this trend, fruits treated with MgO at 0.056% + $CaCl_2$ at 0.032% retained the highest Vitamin C content throughout the storage period, while control fruits exhibited the lowest content.

The combined application of magnesium and calcium had a pronounced effect on maintaining Vitamin C content during storage. This study highlights that pre-harvest Mg + Ca treatments delayed the loss of ascorbic acid by enhancing the fruit's antioxidant capacity and reducing physiological disorders. This defense against oxidative stress helped preserve Vitamin C levels, thereby maintaining fruit quality and extending the post-harvest life of Flame Seedless grapes. These findings reported that calcium minimized physiological disorders and reduced ascorbic acid loss in Superior grapes.

Furthermore, pre-harvest calcium treatments have been shown to effectively maintain ascorbic acid content [15], while magnesium fertilization, as nitrate at 1% or sulfate at 1%, has been reported to enhance Vitamin C content significantly. The foliar application of Mg and Ca thus provides an effective strategy to reduce Vitamin C loss and improve the marketability of Flame Seedless grape clusters over extended storage periods.

Table 23. Effect of **magnesium** and calcium pre-harvest treatments on Vitamin C % of flame grape fruits during 12 days market period storage at (10^0C – 90RH %) in 2022 season.

	Marketing Period days (P)					
Treatments (T)	**D0**	**D03**	**D06**	**D09**	**D12**	**Mean**
Control	5.29	4.84	4.34	3.97	3.15	4.32
MgO (0.028%) W/V	5.72	5.22	4.72	4.30	3.49	4.69
$CaCl_2$ (0.016%) W/V	6.19	5.70	5.40	4.97	4.42	5.33
MgO (0.056%) W/V	6.10	5.60	5.10	4.69	3.81	5.06
$CaCl_2$ (0.032%) W/V	7.75	7.28	6.62	6.25	5.11	6.60
MgO (0.028%) + $CaCl_2$ (0.016%) W/V	6.33	6.36	5.86	5.47	4.67	5.74
MgO (0.056%) + $CaCl_2$ (0.016%) W/V	6.56	6.61	6.24	5.86	4.65	5.98
MgO (0.028%) + $CaCl_2$ (0.032%) W/V	7.96	7.61	7.00	6.63	5.44	6.93
MgO (0.056%) + $CaCl_2$ (0.032%) W/V	8.13	7.92	7.39	7.02	5.65	7.22
Mean	6.67	6.35	5.85	5.46	4.49	
L.S.D at 0.05	**Treatments (T) 0.12**		**M. Periods (P) 0.09**		**Interactions (T x P) 0.23**	

Table 24. Effect of magnesium and calcium pre-harvest treatments on Vitamin C % of flame grape fruits during 12 days market period storage at (10^0C – 90RH %) in 2023 season.

	Marketing Period days (P)					
Treatments (T)	**D0**	**D03**	**D06**	**D09**	**D12**	**Mean**
Control	5.45	4.98	4.47	4.01	3.19	4.42
MgO (0.028%) W/V	5.89	5.37	4.86	4.34	3.53	4.80
$CaCl_2$ (0.016%) W/V	6.37	5.87	5.56	5.02	4.47	5.46
MgO (0.056%) W/V	6.28	5.77	5.25	4.74	3.84	5.18
$CaCl_2$ (0.032%) W/V	7.98	7.50	6.82	6.31	5.16	6.75
MgO (0.028%) + $CaCl_2$ (0.016%) W/V	6.52	6.55	6.04	5.52	4.71	5.87

MgO (0.056%) + $CaCl_2$ (0.016%) W/V	6.75	6.81	6.43	5.91	4.70	6.12
MgO (0.028%) + $CaCl_2$ (0.032%) W/V	8.20	7.84	7.21	6.70	5.49	7.09
MgO (0.056%) + $CaCl_2$ (0.032%) W/V	8.38	8.16	7.61	7.09	5.71	7.39
Mean	6.87	6.54	6.03	5.52	4.53	
L.S.D at 0.05	**Treatments (T) 0.12**		**M. Periods (P) 0.094**		**Interactions (T x P) 0.24**	

13. Total Phenolic Compounds

Grapes are a significant source of phenolic compounds, which exhibit high antioxidant activity and are essential for human nutrition. Phenolic compounds also play a crucial role in determining fruit quality characteristics such as color, taste, and aroma. The results presented in Tables 24 and 25 demonstrate a significant decrease in total phenolic content as the storage market period progressed. However, fruits treated with pre-harvest MgO at 0.056% + $CaCl_2$ at 0.032% consistently exhibited the highest total phenolic content, followed by MgO at 0.028% + $CaCl_2$ at 0.032%, MgO at 0.028% + $CaCl_2$ at 0.016%, and finally the untreated control, which recorded the lowest total phenolic content at the end of the storage period during both seasons.

Interaction data revealed that untreated control fruits experienced a more rapid decline in total phenolic content compared to treated fruits. The superior performance of MgO at 0.056% + $CaCl_2$ at 0.032% in maintaining phenolic content can be attributed to its ability to delay the deterioration process.

Polyphenol oxidase (PPO) activity is known to contribute to tissue browning through the oxidation of phenolic compounds. All pre-harvest treatments resulted in a slower decline in total phenolic content during market storage compared to the control. The retention of phenolic compounds in treated fruits can be linked to reduced respiration, delayed softening, and minimized acidity loss due to the addition of calcium in pre-harvest treatments. Calcium has also been reported to suppress PPO activity during the storage of grape fruits.

Pre-harvest treatments, particularly the combination of Mg and Ca, effectively reduced phenolic losses by delaying the oxidation of phenolic substances mediated by PPO activity. This contributed to improved storability and prolonged market life of *Flame Seedless* grapes. These findings observed increased total phenolic content in grapes treated with pre-harvest foliar calcium applications during cold storage.

Table 25. Effect of magnesium and calcium pre-harvest treatments on Total phenols % of flame grape fruits during 12 days market period storage at (10^0C – 90RH %) in 2022 season.

	Marketing Period days (P)					
Treatments (T)	**D0**	**D03**	**D06**	**D09**	**D12**	**Mean**
Control	162.00	138.47	123.25	109.08	91.23	124.81
MgO (0.028%) W/V	178.67	151.87	131.17	109.93	99.73	134.27
$CaCl_2$ (0.016%) W/V	170.67	145.07	132.03	107.95	93.78	129.90
MgO (0.056%) W/V	201.00	170.85	145.17	123.82	106.53	149.47
$CaCl_2$ (0.032%) W/V	174.67	148.47	132.00	122.97	104.55	136.53
MgO (0.028%) + $CaCl_2$ (0.016%) W/V	179.67	152.72	141.38	134.87	114.18	144.56
MgO (0.056%) + $CaCl_2$ (0.016%) W/V	202.67	172.27	150.17	135.43	106.25	153.36
MgO (0.028%) + $CaCl_2$ (0.032%) W/V	176.00	149.60	144.22	133.45	115.60	143.77
MgO (0.056%) + $CaCl_2$ (0.032%) W/V	207.00	175.95	153.57	143.88	129.20	161.92

Mean	183.59	156.14	139.22	124.60	106.79	
L.S.D at 0.05	**Treatments (T) 4.03**		**M. Periods (P) 3.00**		**Interactions (T x P) 7.73**	

Table 26. Effect of magnesium and calcium pre-harvest treatments on Total phenols % of flame grape fruits during 12 days market period storage at (10^0C – 90RH %) in 2023 season.

	Marketing Period days (P)					
Treatments (T)	**D0**	**D03**	**D06**	**D09**	**D12**	**Mean**
Control	165.24	137.70	117.70	104.76	92.72	123.62
MgO (0.028%) W/V	182.24	151.87	129.09	111.49	93.44	133.63
$CaCl_2$ (0.016%) W/V	174.08	145.07	123.31	112.23	91.76	129.29
MgO (0.056%) W/V	205.02	170.85	145.22	123.39	105.24	149.95
$CaCl_2$ (0.032%) W/V	178.16	148.47	126.20	112.20	104.52	133.91
MgO (0.028%) + $CaCl_2$ (0.016%) W/V	183.26	152.72	129.81	120.18	114.64	140.12
MgO (0.056%) + $CaCl_2$ (0.016%) W/V	206.72	172.27	146.43	127.64	115.12	153.63
MgO (0.028%) + $CaCl_2$ (0.032%) W/V	179.52	149.60	127.16	122.58	113.43	138.46
MgO (0.056%) + $CaCl_2$ (0.032%) W/V	211.14	175.95	149.56	130.53	122.30	157.90
Mean	187.26	156.05	132.72	118.33	105.91	
L.S.D at 0.05	**Treatments (T) 3.46**		**M. Periods (P) 2.57**		**Interactions (T x P) 6.62**	

3 Conclusion

The foliar application of combined calcium and magnesium treatments demonstrated superior efficacy compared to their individual applications. Pre-harvest treatments comprising magnesium oxide (MgO) at 0.056% combined with calcium chloride ($CaCl_2$) at 0.032% proved the most effective, followed by MgO at 0.028% + $CaCl_2$ at 0.032%, MgO at 0.028% + $CaCl_2$ at 0.032%, and MgO at 0.028% + $CaCl_2$ at 0.016%. These combined treatments significantly enhanced yield, controlled postharvest decay, and mitigated compositional changes by delaying both physical and chemical alterations, reducing respiration rates during cold market storage, and extending postharvest shelf life. A higher ratio of Mg to Ca emerged as a reliable indicator for improving yield, fruit quality, and the marketability of "Flame" grapes. These pre-harvest foliar applications are safe, simple, and present a promising strategy for maintaining fruit quality and extending the market life of "Flame" grape clusters, particularly for long-distance shipping.

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