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Optimizing Budburst and Yield in Superior Seedless Grapevines Using Supplementary Dormancy-Breakers

Gawish, M. S.[1*] and Marwa M. Mosallam[2]

[1]Horticulture Department, Faculty of Agriculture, Damietta University. Damietta, Egypt.
[2]Department of plant production, Faculty of Environmental Agricultural Sciences, Arish University, North Sinai, Egypt.

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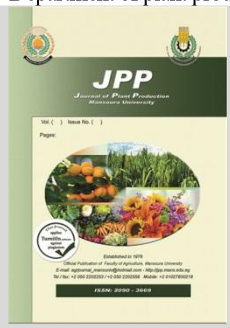

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ABSTRACT

In this study, superior Seedless grapevines were pruned during the winter to retain 10 fruit canes (FCs), each with 10 buds. On 8th of January, all vines were treated with a 5% hydrogen cyanamide (HC) spray, serving as the control treatment. For the four additional treatments, the vines received the same HC spray, supplemented by an additional dormancy-breaking agent (SDBA) applied on 16th of January to the basal five buds of each FC to promote budburst. The SDBA treatments comprised either HC (2.5%), potassium nitrate (KNO_3; 2%), ammonium nitrate (NH_4NO_3; 2%), or zinc sulfate ($ZnSO_4$; 2%). By mid-March, shoot and cluster thinning was conducted to retain the six most vigorous shoots per FC and the largest 30 clusters per vine. The results indicated that all supplemental dormancy-breaking treatments enhanced budburst and bud fertility compared to the control (5% HC alone). These treatments also increased yield per vine and cluster weight. Furthermore, they significantly improved 100-berry weight, berry firmness, detachment force, juice TSS/acid ratio, leaf number per vine and per shoot, leaf-to-cluster ratio, as well as the length and thickness of new canes relative to the control.

Keywords: Grapes, Dormex, potassium nitrate, ammonium nitrate, zinc sulphate, budburst, production, quality.

INTRODUCTION

Grapevine (*Vitis vinifera* L.) is one of the world's most valuable and widely cultivated fruit crops, forming the economic backbone of many horticultural industries. In Egypt, grapes rank second only to citrus in importance, with vineyard acreage expanding steadily to 197925 feddans and an annual production of approximately 1.92 million tons (FAOSTAT, 2023).However, the cultivation of temperate fruit species such as grapevine in warm or subtropical regions often encounters physiological challenges related to insufficient winter chilling. Under mild winter conditions, bud dormancy release can be incomplete, resulting in delayed, uneven, or weak budburst and reduced vine vigor (Mauget and Rageau, 1988 and Cook and Jacobs, 2000). This problem has intensified in recent decades due to global warming, which has shortened or eliminated the chilling period required for proper dormancy fulfillment. Hence, Dominguez *et al.* (2024) demonstrated that warmer winter and spring temperatures advanced phenology, disrupted bud metabolism, and reduced yields in red grape cultivars. Similarly, Ramos *et al.* (2022) reported that changing temperature regimes are already affecting the suitability of traditional grape-growing regions, underscoring the need for adaptive viticultural practices to sustain productivity under evolving climates.

To mitigate the effects of insufficient chilling, dormancy-breaking agents (DBAs) which have been widely applied for over three decades to promote earlier and more uniform budburst. Hydrogen cyanamide (HC, H_2CN_2) remains the most effective and commonly used compound, though alternatives such as thiourea, urea, and potassium nitrate (KNO_3) have also been investigated (Abou-Qaoud, 2004 and Vidal-Lezama *et al.*, 2007).

Recent biochemical evidence indicates that HC functions primarily by transient inhibition of catalase, promoting hydrogen peroxide (H_2O_2) accumulation, which activates oxidative and metabolic pathways that trigger bud reactivation (Pérez and Lira, 2005 and Jamshidian *et al.*, 2024).

Beyond HC, nutrient-based dormancy enhancers have received renewed attention for their dual roles in dormancy release and metabolic stimulation. Potassium-containing fertilizers including potassium nitrate and potassium sulfate have been shown to enhance sugar metabolism, improve fruit quality, and increase vegetative vigor in grapevines (Hu *et al.*, 2023; Wang *et al.*, 2024). In "Superior Seedless" grapevines, dual applications of HC (5%) to basal buds and full fruit canes significantly improved basal budburst, vegetative growth, and renewal spur development (Mahmoud *et al.*, 2015 and Sourial *et al.*, 2015). Such strategies minimize the dependence on external spurs and optimize cane productivity in warm climates.

Recent reviews on grapevines cold tolerance and stress adaptation highlight several regulatory networks and molecular pathways such as abscisic acid (ABA) modulation, reactive oxygen species (ROS) signaling, and carbohydrate remobilization—that govern dormancy release and environmental responsiveness (Chong *et al.*, 2023 and Wang *et al.*, 2024). These findings provide mechanistic insights into how DBAs and nutrient-based treatments might compensate for natural chilling deficits.

Given the increasing frequency of mild winters in Egypt, the development of localized, efficient dormancy-breaking protocols has become vital for sustainable grape production. Therefore, the present study investigates the effects of locally applied dormancy-breaking agents potassium nitrate (KNO_3), ammonium nitrate (NH_4NO_3), zinc

* **Corresponding author.**
E-mail address: msagawish@du.edu.eg
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sulfate ($ZnSO_4$), and hydrogen cyanamide (HC) targeted to the basal regions of "Superior Seedless" fruit canes following a standard full-cane HC application. We hypothesize that targeted basal bud stimulation will enhance budburst efficiency, leading to improved shoot growth and yield uniformity under suboptimal chilling conditions.

MATERIALS AND METHODS

The research was executed in a private commercial vineyard situated in El-Baalwa, Kassasien, within the Ismailia Governorate of Egypt, during the years 2023 and 2024. The study concentrated on Superior Seedless (*Vitis vinifera* L.) grapevines, which were 14 years old and planted with a spacing of 2 x 3 meters in sandy soil. These grapevines were cultivated on Parron-type arbors and managed using the cane pruning method. During the research period, the grapevines were supported by a drip irrigation system, demonstrated robust growth, and remained in excellent health. They were also managed according to the standard horticultural practices recommended for vineyards. Table 1 outlines the vineyard soil's physical and chemical properties, which were fairly uniform.

Table 1. Main physical properties and chemical constituents of the vineyard soil.

Main physical properties										
Particle size distribution (%)						Textural Class		Gravel (%)		SP* (%)
Sand		Silt		Clay						
94.7		1.6		3.7		Sand		2.5		23
Main chemical constituents										
pH	EC	Cations (meq. /l)				Anions (meq. /l)				SAR**
	ds/m	Ca^{++}	Mg^{+}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{-}	SO_4^{--}	Cl^{-}	
8.30	2.7	8.5	7.5	14.5	0.3	0.0	8.0	8.3	14.5	5.1
Available levels of nutrients (ppm)								O.M		$CaCO_3$
N	P	K		Fe	Zn	Mn	Cu	(%)		(%)
63.00	2.65	54.00		2.16	1.14	0.89	2.33	0.12		5.20

*) Saturation percentage **) Sodium Adsorption Ratio (SAR)

The study evaluated the efficacy of hydrogen cyanamide (HC), sold as Dormex (49% hydrogen cyanamide formulation), at concentrations of 2.5% and 5%; potassium nitrate (KNO_3; with 13% nitrogen and 44% potassium by weight) at 2%; ammonium nitrate (NH_4NO_3) at 2%, and zinc sulfate ($ZnSO_4$) at 2%. On 8th of January, a 5% solution of hydrogen cyanamide was applied to the entire fruit canes (FCs) of all the vines under investigation as a control. Subsequently, on 16th of January, separate applications of 2.5% hydrogen cyanamide, 2% KNO_3, 2% NH_4NO_3, and 2% $ZnSO_4$ were made to the basal five buds of the FCs of all vines that had previously received the 5% HC treatment. Each of the five treatments was applied to nine vines, distributed across three replicates during the study period (2023 and 2024) (5 treatments * 3 replicates * 3 vines per replicate = 45 vines). A randomized complete block design was employed to set up the treatments.

In this experiment evaluation of tested treatments was performed through the following parameters:

Bud behavior:

Budburst is identified as the point when buds on designated fruiting canes achieve the "green tip" stage, and this phase was assessed. The development of budburst and bud fertility was tracked at each bud location on every FC using the following equation

$$\textbf{Budburst (\%)} = \frac{\textbf{Number of opened buds/vine}}{\textbf{Bud load per vine}} \times 100$$

$$\textbf{Bud fertility (\%)} = \frac{\textbf{Number of fruitful shoots/vine}}{\textbf{Total number of shoots/vine}} \times 100$$

Thinning of shoots and clusters commenced on 15th of March, with the selection of the six most vigorous shoots on each fruit cane (6 shoots per FC x 10 FCs per vine = 60 shoots per vine). Furthermore, the finest 30 clusters were retained on each vine across both seasons.

Yield components

At a minimum of 14% SSC, clusters were harvested when berries maturity was commercially suitable. Yield was determined in kg by multiplying thirty clusters per vine times the average cluster weight (g) and the hypothetic yield/fed (ton).

Clusters characteristics

At harvest, three representative clusters were collected from each vine, resulting in nine clusters per replicate. Samples were transported to the laboratory within two hours for quality evaluation. Cluster weight (g) and rachis weight (g) were recorded. Cluster length and width (cm) were measured using a Vernier caliper, and the number of berries per cluster was counted manually.

Physio-chemical characteristics:

A random sample of 100 berries was selected to determine the average berry weight (g) and assess berries quality. Berry firmness (g) and berry detachment force (g) were measured using a handheld fruit firmness tester (Model FT-327, Italy). The ratio of total soluble solids (TSS) to titratable acidity of berry juice was also determined.

Vegetative growth parameters

The number of leaves per shoot was recorded during the active growth period in September of each season using twenty shoots per vine. The mean number of leaves per vine was obtained by multiplying the average number of leaves per shoot by sixty shoots per vine. The leaf-to-cluster ratio was calculated by dividing the total leaf number per vine by the total number of clusters per vine.The length and thickness of new canes were measured in centimeters using a ruler and a Vernier caliper, respectively.

Following leaf abscission, cane samples were collected from the middle portion of current-season shoots to determine total carbohydrate content according to the procedure described by Michel *et al.* (1956). The weight of pruning wood (kg) obtained during winter pruning was also recorded.

Determination of nutrient contents:

Leaf petiole samples from each replicate were collected, oven-dried at 70°C until constant weight, and finely ground. A 0.5 g subsample was digested in perchloric acid ($HClO_4$) and diluted to 50 ml with distilled water following the method of A.O.A.C. (2015). Nitrogen concentration (N%) was determined using the Kjeldahl method (Jackson, 1958), phosphorus (P%) was determined spectrophotometrically at

660 nm (Olsen *et al.*, 1954), and potassium (K%) was measured using a flame photometer (Horneck and Hanson, 1998). Zinc concentration (ppm) was quantified using atomic absorption spectrophotometry (David, 1958).

Statistical analysis

The obtained data were subjected to statistical analysis using a randomized complete block design (RCBD) and one-way analysis of variance (ANOVA) following the procedures outlined by Snedecor and Cochran (1990). Data analysis was conducted using the CoStat statistical software package, and mean separations were performed using the Least Significant Difference (LSD) test at the 5% probability level.

RESULTS AND DISCUSSION

Bud Behavior

Budburst

All supplemental dormancy-breaking treatments markedly enhanced budburst in “Superior Seedless” grapevines compared with the control (Tables 2 and 3). Control vines recorded budburst rates of 71.97% and 70.33% during the first and second seasons, respectively. In contrast, vines receiving supplemental treatments exhibited significantly higher values, ranging from 90.97% to 93.30% in the first season and from 89.67% to 94.62% in the second.

The mean budburst percentage of the basal five buds in the control treatment was 71.30% and 69.33% in the first and second seasons, respectively, whereas the supplemental treatments ranged from 89.30% to 92.64% in the first season and from 89.33% to 93.33% in the second. All supplemental applications produced statistically significant increases in budburst of the basal buds compared with the control (HC at 5% applied on 8th of January). The combined application of HC (5%) with an additional 2.5% HC treatment produced the greatest improvement in budburst (92.64%) during both the 2023 and 2024 seasons. Similarly, HC (5%) followed by $ZnSO_4$ (2%) enhanced budburst in 2023 but was less effective in 2024. The best performance overall was achieved with HC (5%) combined with KNO_3 (2%) in the second season, recording 93.33% budburst.

Bud position significantly affected budburst, especially in the first season. Control vines (HC 5%, applied 8th of January) showed the lowest budburst (66.60–76.60% in 2023 and 66.66–76.66% in 2024), while SDBA treatments achieved 80–100% in 2023 and 86.66–100% in 2024. These results confirm the importance of combined treatments under warm-winter conditions like those in Egypt. Budburst improvements from 70–72% in controls to 90–94% with supplemental sprays, particularly in basal buds, agree with Mahmoud *et al.* (2015) and Sourial *et al.* (2015), who reported enhanced basal budburst in ‘Superior Seedless’ after sequential HC sprays.

The enhancement is mainly attributed to hydrogen cyanamide’s (HC) inhibition of catalase, causing H_2O_2 accumulation that triggers oxidative and respiratory activation. Similar responses were noted by Khalil *et al.* (2019) and Jamshidian *et al.* (2024), linking HC to oxidative metabolism and gene activation for bud reactivation. Nutrient supplements such as KNO_3 and $ZnSO_4$ likely boosted nutrient uptake, enzyme activity, and hormonal balance (Daccak *et al.*, 2021 and Hiejima *et al.*, 2025). HC combined with biostimulants improved ROS and nitric oxide signaling, enhancing budbreak uniformity (Venter *et al.*, 2024).

Table 2. Response of budburst (%) at different bud positions on fruit canes (FCs) of Superior Seedless grapevines to hydrogen cyanamide (HC), KNO_3, NH_4NO_3 and $ZnSO_4$ treatments (first season, 2023)

Treatments	Bud position (BP) on the fruit canes										Treat. av.
	1 basal	2	3	4	5	6	7	8	9	10	
*Cont. (HC 5% on the whole FCs. on 8th of Jan.)	66.60	70.00	76.60	73.30	70.00	73.30	73.30	70.00	70.00	76.60	71.97
Cont. + HC 2.5% (16th of Jan.)	100.00	93.30	90.00	96.60	83.30	93.30	93.30	96.60	90.00	96.60	93.30
Cont. + KNO_3 2 % (16th of Jan.)	90.00	90.00	90.00	90.00	86.60	96.60	96.60	96.60	90.00	96.60	92.30
Cont. + NH_4NO_3 2% (16th of Jan.)	83.30	86.60	90.00	96.60	90.00	90.00	96.60	96.60	90.00	90.00	90.97
Cont. + $ZnSO_4$ 2% (16th of Jan.)	80.00	90.00	96.60	96.60	100.00	86.60	90.00	100.00	96.60	96.60	93.30
Bud position av. (BP)	83.98	85.98	88.64	90.62	85.98	87.96	89.96	91.96	87.32	91.28	88.37
LSD at 0.05	Treat. = 4.10				Bud position (BP) =5.80			Interaction (Treat. X Bud posit.) =12.96			

*Cont.: H.C. treat. at 5% on 8th of Jan.., all the 1-year-old wood was sprayed. -Vines of all treatments were winter pruned to bear 10 fruit canes, each having 10 buds.

Table 3. Response of budburst (%) at different bud positions on fruit canes (FCs) of Superior Seedless grapevines to some hydrogen cyanamide (HC), KNO_3, NH_4NO_3 and $ZnSO_4$ treatments (second season, 2024)

Treatments	Bud position (BP) on the fruit canes										Treat. av.
	1 basal	2	3	4	5	6	7	8	9	10	
*Cont. (HC 5% on the whole FCs. on 8th of Jan.)	66.66	73.33	66.66	66.66	73.33	73.33	66.66	76.66	66.66	73.33	70.33
Cont. + HC spray 2.5% (16th of Jan.)	93.33	90.00	96.66	93.33	90.00	93.33	86.66	96.66	100.00	90.00	92.99
Cont. + KNO_3 2 % (16th of Jan.)	93.33	96.66	93.33	90.00	93.33	96.66	93.33	93.33	96.66	96.66	94.62
Cont. + NH_4NO_3 2% (16th of Jan.)	86.66	86.66	90.00	96.66	86.66	90.00	90.00	86.66	93.33	90.00	89.67
Cont. + $ZnSO_4$ 2% (16th of Jan.)	86.66	86.66	90.00	93.33	93.33	90.00	93.33	86.66	90.00	90.00	90.00
Bud position av. (BP)	85.33	86.66	87.33	88.00	87.33	88.66	86.00	87.99	89.33	88.00	87.52
LSD at 0.05	Treat. = 4.02				Bud position (BP) = NS			Interaction (Treat. X Bud posit.) =12.73			

* Cont.: H.C. spray at 5% on 8th of Jan.., all the 1-year-old wood was sprayed. -Vines of all treatments were winter pruned to bear 10 fruit canes, each having 10 buds

Bud Fertility

The results presented in Tables 4 and 5 demonstrate that all supplemental dormancy-breaking agent (SDBA) treatments substantially enhanced bud fertility in “Superior Seedless” grapevines compared with the control. In both 2023 and 2024 seasons, the control vines (HC, 5% on 8th of January) recorded the lowest percentages of fruitful buds (20.00% and 21.33%, respectively). In contrast, supplemental SDBA treatments increased bud fertility to 34.31–42.00% in 2023 and 32.00–35.00% in 2024. Among these, the combination of HC (5%) followed by ammonium nitrate (NH_4NO_3, 2%) resulted in the highest fertility (42.00%) in the first season, while $ZnSO_4$ (2%) and KNO_3 (2%) consistently improved bud fertility in both seasons relative to the control.

Regarding the basal five buds, all SDBA treatments markedly enhanced fertility compared to untreated vines across both seasons. The combined HC + NH_4NO_3 (2%) treatment produced the highest fertility rates (29.33% and 22.66% in 2023 and 2024, respectively). $ZnSO_4$ (2%) also improved fertility in the first season (28.66%) but not significantly in the second. As expected, the first basal bud remained non-fruitful in all treatments, indicating its limited developmental potential under field conditions.

Bud position significantly affected fertility, with distal buds showing higher fruitfulness in both seasons. Control vines had the lowest fertility in basal buds, while distal buds (5th–10th nodes) under KNO_3, NH_4NO_3, or $ZnSO_4$ treatments reached 43.00–63.33% in 2023 and 40.00–56.66% in 2024. These improvements under SDBA treatments are linked to enhanced nutrient uptake, metabolic activation, and hormonal balance. Nitrate compounds (KNO_3, NH_4NO_3) promote amino acid and protein synthesis for floral primordia (Hu *et al.*, 2023), while nitrogen supports cytokinin and gibberellin synthesis (Lavee and May, 1997). Potassium aids carbohydrate allocation (Wang *et al.*, 2024), and zinc acts as a cofactor in auxin metabolism (Jamshidian *et al.*, 2024 and Hiejima *et al.*, 2025).

Higher fertility in distal buds agrees with earlier reports linking it to better vascular connections and carbohydrate reserves (Chong *et al.*, 2023). The SDBA–bud position interaction suggests that supplemental nutrients and oxidative signaling can mitigate the apical–basal fertility gradient. Venter *et al.* (2024) similarly found that HC with biostimulants improved floral differentiation in "Crimson Seedless" via ROS and NO signaling.

Table 4. Response of bud fertility (%) at different bud positions on fruit canes (FCs) of Superior Seedless grapevines to some hydrogen cyanamide (HC), KNO_3, NH_4NO_3 and $ZnSO_4$ treatments (first season, 2023)

Treatments	Bud position (BP) on the fruit canes										Treat.
	1 basal	2	3	4	5	6	7	8	9	10	av.
*Cont. (HC 5% on the whole FCs. on 8th of Jan.)	0.00	0.00	6.66	10.00	16.66	30.00	30.00	33.33	33.33	40.00	20.00
Cont. + HC spray 2.5% (16th of Jan.)	0.00	0.00	33.33	43.33	36.66	43.33	46.66	46.66	46.66	46.66	34.31
Cont. + KNO_3 2% (16th of Jan.)	0.00	0.00	23.33	33.33	46.66	50.00	53.33	46.66	56.66	56.66	36.66
Cont. + NH_4NO_3 2% (16th of Jan.)	0.00	20.00	33.33	43.33	50.00	50.00	50.00	56.66	53.33	63.33	42.00
Cont. + $ZnSO_4$ (2% on 16th of Jan.)	0.00	13.33	36.66	43.33	50.00	46.66	50.00	53.33	43.33	43.33	38.00
Bud position av. (BP)	0.00	6.67	26.66	34.66	40.00	44.00	46.00	47.33	46.66	50.00	34.19
LSD at 0.05	Treat. =4.96			Bud position (BP) =7.01			Interaction (Treat. X Bud posit.) =15.68				

*** Cont.: H.C. spray at 5% on 8th of Jan.., all the 1-year-old wood was sprayed. -Vines of all treatments were winter pruned to bear 10 fruit canes, each having 10 buds.**

Table 5. Response of bud fertility (%) at different bud positions on fruit canes (FCs) of Superior Seedless grapevines to some hydrogen cyanamide (HC), KNO_3, NH_4NO_3 and $ZnSO_4$ treatments (second season, 2024)

Treatments	Bud position (BP) on the fruit canes										Treat.
	1 basal	2	3	4	5	6	7	8	9	10	av.
*Cont. (HC 5% on the whole FCs. on 8th of Jan.)	0.00	0.00	3.33	10.00	16.66	26.66	26.66	40.00	46.66	43.33	21.33
Cont. + HC spray 2.5% (16th of Jan.)	0.00	0.00	26.66	33.33	33.33	40.00	50.00	50.00	46.66	40.00	32.00
Cont. + HC spray 2.5% (16th of Jan.)	0.00	0.00	26.66	30.00	40.00	46.66	46.66	50.00	46.66	36.66	32.33
Cont. + KNO_3 2% (16th of Jan.)	0.00	0.00	26.66	40.00	46.66	40.00	56.66	50.00	46.66	43.33	35.00
Cont. + NH_4NO_3 2% (16th of Jan.)	0.00	0.00	20.00	40.00	46.66	43.33	50.00	53.33	40.00	40.00	33.33
Cont. + $ZnSO_4$ (2% on 16th of Jan.)	0.00	0.00	20.66	30.67	36.66	39.33	46.00	48.67	45.33	40.66	30.80
LSD at 0.05	Treat. =3.11			Bud position (BP) = 4.40			Interaction (Treat. X Bud posit.) =9.84				

*** Cont.: H.C. spray at 5% on 8th of Jan.., all the 1-year-old wood was sprayed. -Vines of all treatments were winter pruned to bear 10 fruit canes, each having 10 buds.**

Yield Components

Data in Tables 6 and 7 indicate that all supplemental dormancy-breaking agent (SDBA) treatments significantly enhanced cluster weight, yield per vine, and total productivity per feddan of Superior Seedless grapevines across both seasons. In the first season, potassium nitrate (KNO_3, 2%) and ammonium nitrate (NH_4NO_3, 2%) treatments produced the heaviest clusters (728.66 g and 710.66 g, respectively), representing increases of 25.49% and 24.53% over the control. Similarly, in the second season, vines treated with hydrogen cyanamide (HC, 2.5%) and KNO_3 (2%) yielded 722.33 g and 712.20 g per cluster, marking improvements of 31.29% and 29.25% above the untreated vines. The corresponding yield per vine followed a similar trend, with significant increases ranging from 19.27% to 25.49% in 2023 and from 21.82% to 31.28% in 2024 compared with the control.

Table 6. Response of yield components and cluster characteristics of Superior Seedless grapevines to some hydrogen cyanamide (HC), KNO_3, NH_4NO_3 and $ZnSO_4$ treatments (first season, 2023)

Treatments	Yield/ vine		Hypothetic yield/ fed.		Cluster weight		Cluster length	Cluster width	No. berries/cluster	Rachis weight
	(kg)	**±%	(ton)	**±%	(g)	**±%	(cm)	(cm)		(g)
*Cont. (HC 5% on the whole FCs. on 8th of Jan.)	17.42	-	12.19	-	580.66	-	19.3	10.4	141.33	16.5
Cont. +HC 2.5% (16th of Jan.)	20.74	+21.07	14.51	+21.02	686.66	+20.33	21.6	11.8	157.00	18.6
Cont. + KNO_3 2% (16th of Jan.)	21.86	+25.49	15.30	+25.51	728.66	+25.49	23.7	11.2	158.66	18.1
Cont. + NH_4NO_3 2% (16th of Jan.)	21.30	+24.35	14.91	+24.35	710.66	+24.53	22.6	11.3	157.00	19.1
Cont. + $ZnSO_4$ 2% (16th of Jan.)	20.43	+19.27	14.30	+19.27	680.66	+19.28	22.2	11.2	142.66	19.5
LSD at 0.05	2.71	-	1.46	-	54.24	-	1.34	1.20	13.32	1.09

*** Cont.: H.C. spray at 5% on 8th of Jan.., all the 1-year-old wood was sprayed.**
***±% = increase or decrease % in relation to control.**

Table 7. Response of yield components and cluster characteristics of Superior Seedless grapevines to some hydrogen cyanamide (HC), KNO_3, NH_4NO_3 and $ZnSO_4$ treatments (second season, 2024)

Treatments	Yield / vine (kg)	**±%	Hypothetic yield/ fed. (ton)	**±%	Cluster weight (g)	**±%	Cluster length (cm)	Cluster width (cm)	No. berries/ cluster	Rachis weight (g)
*Cont. (HC 5% on the whole FCs. on 8th of Jan.)	16.50	-	11.55	-	550.16	-	19.20	10.43	131.33	16.53
Cont. + HC 2.5% (16th of Jan.)	21.66	+31.28	15.17	+31.34	722.33	+31.29	21.43	11.16	161.66	18.43
Cont. + KNO3 2 % (16th of Jan.)	21.46	+30.06	15.03	+30.12	712.20	+29.45	21.50	11.56	162.66	17.80
Cont. + NH4NO3 2% (16th of Jan.)	20.10	+21.82	14.07	+21.81	669.96	+21.77	20.23	11.06	149.33	17.50
Cont. + ZnSO4 2% (16th of Jan.)	20.40	+23.64	14.28	+23.63	679.96	+26.86	20.83	11.50	150.66	17.73
LSD at 0.05	1.54	-	1.08	-	49.48	-	1.44	0.55	14.83	1.08

*** Cont.: H.C. treat. at 5% on 8th of Jan.., all the 1-year-old wood was sprayed.**
****±% = increase or decrease % in relation to control.**

Yield and cluster improvements resulted from the stimulatory effects of SDBA treatments on budburst and vegetative growth. Enhanced basal budburst increased fruitful shoots and improved the leaf area-to-fruit ratio, promoting assimilate production and allocation to clusters, which raised cluster and berry weights. Similar results were reported by Mahmoud *et al.* (2015) and Sourial *et al.* (2015) in 'Superior Seedless', using nitrogen- and potassium-based sprays. Potassium's role in osmotic regulation and carbohydrate partitioning also supports higher berry weight (Villette *et al.*, 2020).

Fruit quality

Data presented in Table 8 demonstrate that all supplemental dormancy-breaking agent (SDBA) treatments significantly increased the 100-berry weight of Superior Seedless grapevines compared to the control during both growing seasons. Although variations among the tested treatments were statistically insignificant, all surpassed the control in berry mass. The control vines produced berries weighing 418.33 g and 420.36 g in the first and second seasons, respectively, whereas treated vines recorded values ranging from 451.33–461.00 g in 2023 and 439.10–453.80 g in 2024.

Berry firmness also improved with all supplemental treatments, ranging between 467.40–491.67 g in the first season and 452.33–471.66 g in the second, with the lowest firmness values consistently observed in the untreated vines. Although differences among the supplemental treatments were not statistically significant, all produced firmer berries than the control. Similarly, berry detachment (attachment) force ranged from 700.0–775.0 g in 2023 and 716.66–786.33 g in 2024, with the highest values associated with KNO_3 and NH_4NO_3 treatments during the first season.

In addition, the total soluble solids to titratable acidity (TSS/acid) ratio an indicator of fruit ripening and sensory quality was significantly higher under nitrate-based treatments. In the first season, KNO_3 and NH_4NO_3 produced ratios of 24.37 and 22.94, respectively, compared to 19.96 in the control; in the second season, the same treatments achieved 24.67 and 24.65 versus 22.32 in the control vines. These improvements reflect better sugar accumulation, organic acid metabolism, and enhanced physiological maturity.

The observed increases in berry size, firmness, and TSS/acid ratio under SDBA treatments are linked to improved nutrient assimilation, hormonal balance, and source–sink dynamics following enhanced budburst and vegetative vigor. Nitrate forms of nitrogen (from NH_4NO_3 and KNO_3) stimulate amino acid synthesis, osmotic regulation, and sugar transport, promoting berry enlargement and ripening uniformity (Hu *et al.*, 2023 and Wang *et al.*, 2024). Potassium supports phloem loading and sucrose translocation, improving berry turgor and firmness (Rogiers *et al.*, 2017), while hydrogen cyanamide (HC) enhances photosynthetic activity and assimilate supply during berry growth (Jamshidian *et al.*, 2024 and Venter *et al.*, 2024). Balanced mineral nutrition (Zn^{2+}, K^+, NO_3^-) further contributes to cell wall integrity and firmness, consistent with Dormex-induced quality improvements reported by Guillamón *et al.* (2022).

Recent findings support these mechanisms: foliar KNO_3 increased berry firmness and sugar content (Wu *et al.*, 2021), while nitrogen and temperature interactions affected berry composition through metabolic regulation (Rienth *et al.*, 2021). Nitrate also enhanced berry structural integrity (Jia *et al.*, 2023), and potassium delayed softening via antioxidant activity (Karimi and Mirbaqeri, 2018).

Table 8. Effect of HC spray at 5 % on 8th of Jan., followed by supplemental treatments on the basal halves of fruit canes on 16th of Jan., on some fruit quality parameters of Superior Seedless grape in 2023 and 2024 seasons.

Control and supplemental treatments	100- berries weight (g) 2023	100- berries weight (g) 2024	Berry firmness (g) 2023	Berry firmness (g) 2024	Berry attaching force (g) 2023	Berry attaching force (g) 2024	TSS/acid ratio 2023	TSS/acid ratio 2024
*Cont. (HC 5% on the whole FC. on 8th of Jan.)	418.33	420.36	467.0	452.33	700.00	716.66	19.96	22.32
Cont. +HC (2.5%) 16th of Jan.	453.66	448.56	475.0	466.33	748.33	765.00	21.89	24.32
Cont. + KNO_3 (2%) 16th of Jan.	461.00	439.10	491.67	468.33	775.00	786.33	24.37	24.67
Cont.+NH_4NO_3(2%)16th of Jan.	453.33	452.76	475.0	471.66	761.08	771.66	22.94	24.65
Cont. + $ZnSO_4$ (2%) 16th of Jan.	451.33	453.80	480.0	469.00	746.00	768.33	20.71	22.32
LSD at 0.05	16.33	12.19	30.36	12.97	48.95	24.87	3.49	1.87

All supplemental treatments were applied on the basal half of fruit cane

Vegetative growth

As shown in Table 9, the lowest number of leaves per vine was consistently observed in the control vines, recording 1,646.33 and 1,451.66 leaves during the first and second seasons, respectively. Since leaf number per vine was calculated as the product of average leaves per shoot and total shoots per vine (60 shoots following thinning), all supplemental dormancy-breaking agent (SDBA) treatments markedly increased leaf number. Treated vines produced between 2,329.67 and 2,763.00 leaves in the first season and between 2,270.00 and 2,423.33 in the second—representing increases of 41.51–67.83% and 57.40–66.39% over the control, respectively. The highest leaf counts were recorded in vines treated with potassium nitrate (KNO_3) and additional hydrogen cyanamide (HC) applications.

This notable increase in leaf number can be attributed to the enhanced budburst and shoot growth on the basal nodes of fruiting canes (FCs) induced by the SDBA treatments. Our results is aligned with (Hu *et al.*, 2023; Jamshidian *et al.*, 2024) they reported that, enhanced vegetative vigor likely arose from improved nitrogen and potassium uptake, which promote chlorophyll synthesis, cell expansion, and leaf initiation. Potassium plays a central role in osmotic adjustment and photosynthate translocation, thereby supporting rapid canopy expansion (Rogiers *et al.*, 2017). Similarly, hydrogen cyanamide (HC) stimulates early bud reactivation and accelerates shoot emergence by activating respiratory metabolism and cell division (khalil *et al.*, 2019 and Venter *et al.*, 2024).

Leaf/Cluster Ratio

The leaf-to-cluster ratio, an important index of vine productivity and balance, ranged from 54.87 to 92.11 in the first season and from 48.38 to 80.77 in the second. The control vines exhibited the lowest ratios, while the highest values were achieved with KNO_3 treatment, followed by HC and NH_4NO_3 applications. Intermediate results were observed with $ZnSO_4$-treated vines.

The superior performance of KNO_3 can be attributed to its dual nutrient composition providing both nitrogen (N) and potassium (K), two essential elements for vegetative growth, photosynthetic efficiency, and assimilate partitioning. Nitrate-nitrogen stimulates leaf expansion and chlorophyll biosynthesis, while potassium enhances phloem loading and sugar translocation to developing berries (Wang *et al.*, 2024). Together, these effects optimize the source–sink relationship, resulting in a favorable leaf/cluster ratio and improved yield components.

Recent research underscores the importance of maintaining optimal canopy-to-fruit balance to ensure sufficient carbohydrate reserves for fruit growth and ripening. Teixeira *et al.* (2025) and Ma *et al.* (2025) demonstrated that potassium and nitrogen synergistically improve canopy photosynthetic efficiency and fruit quality traits by modulating stomatal conductance, chlorophyll fluorescence, and carbohydrate metabolism. Similarly, Miccichè *et al.* (2023) reported that a higher leaf/cluster ratio contributes to enhanced photosynthate supply and berry firmness, particularly under high-temperature stress conditions

Table 9. Effect of HC spray at 5 % on 8th of Jan., followed by supplemental treatments on the basal halves of fruit canes on 16th of Jan., on vegetative growth parameters of Superior Seedless grapevines in 2023 and 2024 seasons.

Control and supplemental treatments	No. of leaves/ vine		Leaf/ cluster ratio		Wt. of winter pruning's (kg)		No. of leaves/ shoot	
	2023	2024	2023	2024	2023	2024	2023	2024
*Cont. (HC 5% on the whole FC. on 8th of Jan.)	1646.33	1451.66	54.87	48.38	1.61	1.53	27.44	24.16
Cont. + HC spray 2.5% (16th of Jan.)	2559.33	2333.33	85.30	77.77	2.09	2.04	42.72	32.22
Cont. + KNO_3 2% (16th of Jan.)	2763.00	2423.33	92.11	80.77	2.08	2.10	46.05	33.83
Cont. + NH_4NO_3 2% (16th of Jan.)	2486.00	2270.00	82.86	75.66	2.28	2.19	41.44	31.77
Cont. + $ZnSO_4$ 2% (16th of Jan.)	2329.67	2285.00	77.65	76.16	2.22	2.10	38.83	31.10
LSD at 0.05	114.52	112.39	3.82	3.74	0.36	0.21	1.79	1.41

All supplemental treatments were applied on the basal half of fruit canes.
*** Cont.: H.C. treat. at 5% on 8th of Jan.., all the 1-year-old wood was sprayed.**

Table 10. Effect of HC spray at 5% on 8th of Jan., followed by supplemental treatments on the basal halves of fruit canes on 16th of Jan., on length, thickness and carbohydrate content of new canes of Superior Seedless grapevines (2023 and 2024 seasons.)

Control and supplemental treatments	New canes length (cm)		New canes thickness (cm)		Total carbohydrates (%)	
	2023	2024	2023	2024	2023	2024
*Cont. (HC 5% on the whole FC. on 8th of Jan.)	159.55	154.66	0.83	0.76	25.72	25.82
Cont. + HC spray 2.5% (16th of Jan.)	231.11	227.49	1.20	1.19	29.35	30.52
Cont. + KNO_3 2 % (16th of Jan.)	240.22	239.99	1.26	1.25	29.15	28.04
Cont. + NH_4NO_3 2% (16th of Jan.)	217.89	221.44	1.17	1.16	30.78	29.85
Cont. + $ZnSO_4$ 2% (16th of Jan.)	205.89	208.33	1.17	0.98	27.35	27.37
LSD at 0.05	12.44	9.76	0.08	0.07	0.98	0.96

All supplemental treatments were applied on the basal half of fruit canes.

Weight of Winter Prunings:

According to Table 10, the winter pruning weight varied from 1.61 to 2.28 kg per vine in the first season and from 1.53 to 2.19 kg in the second. The lowest values consistently appeared in the control vines, whereas vines treated with ammonium nitrate (NH_4NO_3) recorded the highest pruning weights in both years. Although differences among the four supplemental treatments were statistically insignificant, all resulted in marked increases of 29.82–41.62% in the first season and 33.33–43.13% in the second relative to the control.

The observed increases in pruning wood weight are consistent with the improved vegetative development metrics—namely, higher leaf number per vine and greater leaf/cluster ratio—seen in the same treatments. Heavier pruning weights typically reflect more vigorous shoot growth and a denser canopy, which in turn indicate enhanced nutrient uptake, particularly of nitrogen and potassium (Khalil *et al.*, 2019 and Mostafa *et al.*, 2023). These nutrients are crucial for promoting shoot elongation, carbohydrate metabolism, and xylem development (Keller, 2020 and Ma *et al.*, 2025).

Furthermore, the increased pruning biomass suggests that supplemental treatments promoted a balanced vegetative–reproductive growth pattern by stimulating basal budbreak and subsequent canopy expansion. This vegetative robustness contributes to vine resilience under warming winters, a factor increasingly emphasized in recent viticultural adaptation studies (Domínguez *et al.*, 2024 and Venter *et al.*, 2024).

Number of Leaves per Shoot:

Data presented in Table 3 demonstrates that all supplemental treatments substantially increased the number of leaves per shoot. In the first season, the treated vines produced between 38.83 and 46.05 leaves per shoot compared with only 27.44 leaves in the control. Similarly, in the second season, treated vines had 31.10–33.83 leaves per shoot versus 24.16 leaves per shoot in untreated vines.

This enhancement in leaf formation per shoot likely results from increased budburst activity and the subsequent vigor of emerging shoots induced by dormancy-breaking agents such as hydrogen cyanamide and nitrate salts. Nitrate (from KNO_3 and NH_4NO_3) stimulates cytokinin synthesis and enhances meristematic activity, thereby promoting internodal elongation and leaf initiation (Hu *et al.*, 2023 and Jamshidian *et al.*, 2024). Hydrogen cyanamide acts by breaking endodormancy, stimulating cell division, and promoting apical dominance early in the season (Khalil *et al.*, 2019 and Venter *et al.*, 2024).

Vigor of New Canes:

Results in Table 10 indicates that all supplemental treatments produced markedly longer and thicker new canes compared with the control. Control vines produced new canes averaging 159.55 cm and 154.66 cm in length during 2023 and 2024, respectively, whereas treated vines exhibited cane lengths ranging from 205.89 to 240.22 cm in the first season and 208.30 to 239.99 cm in the second. Cane diameter followed a similar trend, with control vines measuring only 0.83 cm and 0.76 cm in thickness compared with 1.17–1.26 cm (first season) and 0.98–1.25 cm (second season) in treated vines.

The carbohydrate content of new canes also increased significantly, rising from 25.72–25.82% in the control to 27.35–30.78% and 27.37–30.52% in the first and second seasons, respectively. This accumulation of carbohydrates indicates a stronger photosynthetic source and more efficient assimilate translocation to developing tissues, likely facilitated by potassium-mediated phloem loading and improved vascular function (Mostafa *et al.*, 2023 and Wang *et al.*, 2024).

Enhanced cane vigor and carbohydrate storage have critical implications for subsequent productivity, as they provide the energy reserves necessary for budburst and fruiting in the following season (Rogiers, 2017 and Keller, 2020). Similar findings were reported by Villette *et al.* (2020) and Wang *et al.* (2021), who observed that nitrogen–potassium synergy improved vegetative vigor, lignification, and carbohydrate metabolism in grapevines under Mediterranean and subtropical conditions.

The present results clearly demonstrate that applying supplemental dormancy-breaking agents particularly KNO_3 and NH_4NO_3 in conjunction with standard hydrogen cyanamide treatment enhances vine vigor by promoting uniform budburst, increased canopy development, and greater carbohydrate reserves. These physiological improvements translate into higher yield potential, improved fruit quality, and enhanced resilience to climate-induced dormancy irregularities.

Vegetative growth responses also revealed significant increments in shoot length, cane thickness, leaf number, and pruning weight.

Leaves nutrient content:

As presented in Table 11, significant differences were observed in the macronutrient (N, P, K) and micronutrient (Zn) contents of grapevine leaves and woody tissues under different supplemental dormancy-breaking agent (SDBA) treatments across the two growing seasons (2023 and 2024). The data clearly indicate that nutrient uptake and accumulation patterns were markedly influenced by the applied treatments.

Control vines showed the lowest nitrogen levels (2.03%), while those treated with hydrogen cyanamide (HC, 2.5%) recorded the highest (2.19–2.22%). The rise in nitrogen content under HC is linked to its stimulatory effects on bud activity, root uptake, and metabolism. HC enhances enzymes involved in nitrogen assimilation—such as nitrate reductase and glutamine synthetase—promoting amino acid and protein synthesis (Khalil *et al.*, 2019; Jamshidian *et al.*, 2024; Venter *et al.*, 2024), which supports greater vegetative growth and pruning weights.

KNO_3, NH_4NO_3, and $ZnSO_4$ also improved nitrogen content, though less than HC. Nitrate-based treatments enhance cytokinin synthesis, photosynthesis, and carbon–nitrogen coordination (Villette *et al.*, 202 and Ma *et al.*, 2025), aiding vine vigor under warm-winter conditions.

For phosphorus, control vines had the lowest values (~0.294–0.298%), while HC (2.5%) showed the highest (0.387–0.388%), followed by $ZnSO_4$ (~0.332–0.336%). Phosphorus supports root development, ATP synthesis, and energy transfer during bud break (Keller, 2020; Mostafa *et al.*, 2023). Enhanced P uptake under HC and $ZnSO_4$ suggests improved root function and membrane permeability (Hu *et al.*, 2023 and Tan and Li, 2025).

Potassium ranged from 1.18–1.41% across treatments, with minor variation. Also, SDBA affected on K accumulations and posting it moderately compared with control , potassium remains crucial for nutrient translocation, osmotic balance, and sugar transport, enhancing berry firmness and productivity (Rogiers *et al.*, 2017 and Wang *et al.*, 2024).

Zinc levels varied more distinctly: control vines had the lowest (~33.4 ppm), while $ZnSO_4$ (2%) achieved the highest (50.9–51.1 ppm). HC, KNO_3, and NH_4NO_3 also increased Zn slightly. Zinc is essential for auxin synthesis, enzyme activation, and protein formation, supporting shoot elongation and fruit set (Daccak *et al.*, 2022 and Bellon *et al.*, 2025). Improved Zn nutrition likely enhanced hormonal balance and photosynthetic efficiency.

Overall, HC (2.5%) was most effective in boosting nitrogen and phosphorus, while $ZnSO_4$ (2%) excelled in improving zinc nutrition. These enhancements strengthen photosynthetic capacity, assimilate production, and reserve accumulation key for sustained productivity under climate stress (Rienth *et al.*, 2022 and Dominguez *et al.*, 2024). The increased nutrient content under SDBA treatments corresponded with higher leaf/cluster ratios, cane vigor, and pruning weights, confirming improved vine balance and long-term performance (Villette *et al.*, 2024 and Teixeira *et al.*, 2025).

Overall, the results highlight the effectiveness of combining HC with other dormancy-breaking agents in mitigating the negative impacts of warm winters and climate variability on “Superior Seedless” productivity. While HC remains the most consistent agent, potassium and ammonium nitrate provide synergistic effects by supplying essential nutrients, whereas zinc sulfate offers metabolic support through micronutrient activity. These findings support integrated chemical strategies as a practical tool to ensure sustainable grape production under climate change scenarios (Atak,2024).

Future research should explore the optimal concentrations, timing, and combinations of these agents to balance efficacy and environmental safety. Moreover, coupling field trials with molecular analyses (transcriptomic, metabolomic, and epigenetic) will further clarify the mechanisms underlying bud dormancy release and help develop less toxic HC alternatives.

Table 11. Effect of HC spray at 5% on 8th of Jan.., followed by supplemental treatments on the basal halves of fruit canes on 16th of Jan., on mineral content of new canes of Superior Seedless grapevines (2023 and 2024 seasons)

Treatments	First season 2023				Second season 2024			
	N %	P %	K %	Zn ppm	N %	P %	K %	Zn ppm
*Cont. (H.C. 5% on whole 1-year-old wood on 8th of Jan.)	2.03 e	0.294 e	1.18	33.46 e	2.03 c	0.298 e	1.20	33.43 e
Cont. + H.C. 2.5% on the basal 5 buds on 16th of Jan.	2.19 a	0.387 a	1.38	42.20 b	2.22 a	0.388 a	1.41	43.18 b
Cont. + KNO_3 on the basal 5 buds (2%) on 16th of Jan.	2.16 b	0.317 c	1.26	38.56 c	2.20 a	0.328 c	1.28	38.91 d
Cont. + NH_4NO_3 on the basal 5 buds (2%) on 16th of Jan.	2.09 d	0.298 d	1.27	38.35 d	2.18 b	0.304 d	1.27	38.97 c
Cont. + $ZnSO_4$ on the basal 5 buds 2% on 16th of Jan.	2.12 c	0.332 b	1.27	50.95 a	2.17 b	0.336 b	1.35	51.15 a
LSD at 0.05	0.02	0.002	NS	0.02	0.02	0.003	NS	0.02

CONCLUSION

Supplemental dormancy-breaking sprays significantly improved budburst, fertility, yield, and berry quality of "Superior Seedless" grapevines compared with HC (5%) alone. Potassium nitrate and ammonium nitrate were most effective, particularly in enhancing basal budburst and fertility, leading to stronger vegetative growth and higher yields. These findings suggest that integrating nutrient-based SDBAs with conventional HC sprays can mitigate the negative effects of insufficient chilling under warm-winter conditions and support sustainable grape production. Further optimization of dosage and timing is recommended to maximize efficiency and reduce reliance on HC.

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تحسين تفتح العيون والمحصول في عنب السوبيريور سيدلس بإستخدام معاملات كسر السكون الإضافية

محمد سعد جاويش[١] ومروة مسلم محمد مسلم [٢]

[١]قسم البستنة كلية الزراعة جامعة دمياط. دمياط، مصر.

[2]قسم الإنتاج النباتي، كلية العلوم الزراعية البيئية، جامعة العريش، شمال سيناء، مصر

الملخص

في هذه الدراسة، تم تقليم كروم العنب صنف (سوبيريور سيدلس) خلال فصل الشتاء بحيث يُحتفظ بـ ١٠ قصبات ثمرية (FCs) تحتوي كل منها على ١٠ عيون في ٨ يناير تمت معاملة جميع الكروم برش محلول سياناميد الهيدروجين (HC) بتركيز ٥٪، والذي اعتُمد كمعاملة مقارنة (الكنترول). أما في أربع معاملات إضافية فقد تم رش الكروم بنفس محلول الـ HC، مع تطبيق مادة إضافية لكسر السكون (SDBA) في ١٦ يناير على العيون الخمس القاعدية لكل قصبة ثمرية بهدف تحفيز تفتح العيون. شملت معاملات الـ SDBA أحد المواد التالية: سياناميد الهيدروجين (HC) بتركيز ٢,٥٪و نترات البوتاسيوم (KNO_3) بتركيز ٢٪ ونترات الأمونيوم (NH_4NO_3) بتركيز ٢٪و كبريتات الزنك ($ZnSO_4$) بتركيز ٢٪ .بحلول منتصف شهر مارس تم إجراء عملية خف النموات والعناقيد بحيث يُحتفظ بـ ستة نموات قوية لكل قصبة ثمرية و٣٠ عنقودًا كبيرًا لكل كرمة. أظهرت النتائج أن جميع معاملات كسر السكون الإضافية عززت من نسبة تفتح العيون وخصوبتها مقارنة بمعاملة الشاهد (٥٪ HC فقط). كما زادت هذه المعاملات من محصول الكرمة ووزن العنقود .علاوة على ذلك، أدت إلى تحسين معنوي في وزن ١٠٠ حبة، وصلابة الحبة، وقوة انفصالها، ونسبة المواد الصلبة الذائبة الكلية إلى الحموضة في العصير(TSS/Acid Ratio) ، بالإضافة إلى زيادة عدد الأوراق لكل كرمة ولكل نمو، ونسبة الأوراق إلى العناقيد، وطول وسمك القصبات الحديثة مقارنة بمعاملة الكنترول.