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RESEARCH PAPER

GroCel (AVG) Enhances Fruit Set and Yield in ‘0900 Ziraat’ Cherries While Providing a Stabilizing Effect under Climate Variability

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Abstract

Our research examined the effects of different doses of GroCel [15% aminoethoxyvinylglycine (AVG), ReTain] on fruit set, yield, and quality parameters of ‘0900 Ziraat’ cherry trees across two distinct locations (Eğirdir and Akşehir) during the 2023-2024 growing seasons under varying climatic conditions. Based on our results, application timing (30-50% flowering period) and dose rate significantly influenced fruit set and yield in both locations ($P<0.05$). The highest application rate (830 g ha^{-1}) consistently exhibited superior efficacy, resulting in a 147% increase in fruit set at Eğirdir (4.80% compared to 1.94% in the control) and an over 600% increase at Akşehir in 2024. Corresponding yield improvements were equally substantial, with 220% increase at Eğirdir and over 110% at Akşehir. Effects on fruit quality parameters varied by location and season. At Eğirdir, physical fruit properties remained largely unaffected across treatments, while Akşehir showed significant decreases in fruit weight and size with increasing AVG doses. Chemical properties showed modest changes, with control treatments generally exhibiting higher soluble solids content (SSC). Importantly, fruit color parameters were not significantly affected by AVG application at either location, or no phytotoxicity or adverse effects on pollinator activity were observed. Climate conditions significantly influenced treatment efficacy, with the protective effect of AVG against temperature fluctuations particularly evident at Eğirdir in 2024, where rapid temperature shifts during flowering severely compromised fruit set in untreated trees. We conclude that GroCel application at 830 g ha^{-1} during the 30-50% flowering period represents an effective management strategy for stabilizing ‘0900 Ziraat’ cherry production, particularly in regions experiencing climate variability. The substantial yield benefits outweigh modest reductions in fruit size and SSC, making this approach commercially valuable for the export-oriented cherry cultivar that typically experiences yield fluctuations.

1. Introduction

Cherry cultivation represents a small portion of global fruit production and acreage, earning it classification as a luxury fruit despite its limited growing regions due to climate constraints (Sarısu, 2017). As the homeland of cherry species, Türkiye holds significant advantages in the cherry industry due to its suitable climate and global demand that exceeds supply. According to FAO (2023), Türkiye leads worldwide cherry production, with approximately 14% occurring in the Isparta and Konya provinces (TUIK, 2024). The ‘0900 Ziraat’ variety, also known as the ‘Turkish Cherry,’ is the most valuable export cultivar in the region. Although it produces high-quality fruit, it is self-incompatible and typically has low yields (Sarısu, 2017), posing challenges for sustainable production. Since sustainable cherry cultivation relies on stable yields, the '0900 Ziraat' variety's inconsistency highlights the need to better understand the physiological factors affecting fruit set. Increasing climate variability has intensified interest in how temperature changes during flowering impact fertilization and fruit set, leading researchers to focus on the physiological mechanisms involved (Aşkın and Sarısu, 2020).Climate change has exacerbated yield fluctuations in the commercially important '0900 Ziraat' variety, prompting numerous studies investigating causes and potential solutions (Aşkın and Sarısu, 2020; Beppu et al., 1997, Beppu and Kataoka, 2011; Postweiler et al., 1985; Sarısu and Aşkın, 2014; Sheard, 2008). Research conducted in Shanghai reported that underdeveloped seed coats and embryo sacs were identified as causes of poor cherry fruit set (ShiPing et al., 2004), while Mert and Soylu (2007) observed abnormal seed coat development in many female organs of the '0900 Ziraat' cultivar despite sufficient pistil numbers and normal pollen tube development. Emre (2011) noted that aging periods for seed drafts of '0900 Ziraat' and Sweet Heart cherry cultivars were 7-8 days, with effective pollination periods documented as 4 days for both cultivars. It has been established that temperature significantly influences seed coat viability, with high temperatures during flowering negatively affecting fruit set by shortening viability periods, while lower temperatures extend this period, as documented by several researchers (Beppu and Kataoka, 2011; Cerovic and Ruzic, 1992; Hedhly et al., 2007; Sarısu, 2017). Postweiler et al. (1985) documented that seed viability varies between 1-2 days at a constant 20°C but increases to 5 days at 5°C, while Beppu et al. (1997) demonstrated that rapid temperature increases from 15°C to 25°C within two days after anthesis results in increased numbers of degenerated embryo sacs. Sarısu (2017) concluded from their research that a 1°C increase in average flowering period temperatures can cause approximately 4% yield loss.

Given these temperature-related challenges to seed viability, researchers have explored various biochemical interventions to counteract these negative effects and improve fruit set outcomes. In this regards, various plant growth regulators (PGRs) and polyamines can affect seed coat viability when applied during autumn or flowering (Beppu et al., 2005; Sanzol and Herrero, 2001; Zhang et al., 2018). Exogenous GA_3 application during flowering decreases seed coat viability (Beppu et al., 2005; Sabir et al., 2021), while endogenous GA_3 increases embryo sac longevity (Herrero, 1992; Sanchez et al., 2004). Ethylene applications during flowering reduce seed coat viability (Stösser and Anvari, 1982), whereas ethylene inhibitors can improve fruit set by extending effective pollination time (Ağlar et al., 2014; Bound et al., 2013; Crisosto et al., 1986). AVG, an ethylene inhibitor that prevents 1-aminocyclopropanecarboxylic acid (ACC) synthesis (Bregoli et al., 2002), is available commercially as ReTain containing 15% AVG (Rath and Prentice, 2004). Applied 1-4 weeks before harvest in climacteric fruits, AVG delays abscission and senescence by affecting ethylene biosynthesis, reducing quality loss in many crops (Çetinbaş et al., 2016; Kim et al., 2004; Martinez-Romero et al., 2007; Pasha et al., 2017; Yildiz et al., 2012). Some studies suggest that applying AVG during flowering may increase fruit set by prolonging seed viability (Bound et al., 2013; Webster et al., 2006), with Bound et al. (2013) demonstrating improved fruit set in Regina and Kordia cherries when AVG was applied at 30% and 80% flowering.

Despite these advances, research on improving fruit set in chronically low-yielding cherry cultivars remains limited, warranting further investigation. This need is particularly pressing in Türkiye's major cherry-growing regions around Isparta and Konya, where climate crisis-induced temperature fluctuations during pollination and fertilization periods have intensified, resulting in decreased fruit set. These reductions harm both producers and the national economy, especially affecting the export-oriented '0900 Ziraat' variety. Therefore, this study aims to determine the effects of GroCel (ReTain, 15% AVG) on fruit set, yield, and fruit quality characteristics of the '0900 Ziraat' variety in two different locations, Isparta-Eğirdir and Konya-Akşehir, addressing a critical gap in current agricultural practices for this economically significant crop.

2. Material and Methods

2.1. Characteristics of the research orchards

The research was carried out in two locations in Eğirdir (Isparta) and Akşehir (Konya) districts in 2023-2024. The Eğirdir site was located at 37°44'14.45" N, 30°45'26.47" E coordinates and at an altitude of 913 m between Eğirdir Lake and Kovada Lake, at the northern end of the Bogazova Valley, in the 10-year-old '0900 Ziraat' cherry orchard of the Serpil Enterprise of the Fruit Research Institute (MAREM). The Akşehir site was located at 38°26'55.42" N, 31°19'48.41" E coordinates and at an altitude of 976 m in the 8-year-old '0900 Ziraat' private grower orchard in Akşehir district of Konya province. Soil analysis of the cherry orchards in both locations was carried out. Samples were taken to determine the soil properties of the research area. Soil analyses were carried out in the soil analysis laboratory of MAREM. In both years, fertilisation was carried out according to the results of the soil analysis of the research area.

2.2. Plant material and plant growth regulator

The '0900 Ziraat' cherry variety was used at both sites. '0900 Ziraat' is a variety with a vigorous and spreading tree. The fruit is very large, heart-shaped, the skin is bright dark red, the flesh is pinkish red and very firm. The late '0900 Ziraat' is called 'Turkish Cherry' and is very important in terms of production and export in Türkiye. In the study, different doses of GroCel (ReTain, 15% AVG) PGR were used to increase fruit set.

2.3. Method

At both locations, experiments were set up according to a randomized block design with 4 replicates and 4 trees in each replicate. Healthy trees with uniform growth were selected and flower counts were carried out on the selected trees. GroCel (ReTain 15% AVG) was applied at doses of 830 g ha^{-1}, 700 g ha^{-1}, 550 g ha^{-1} and 400 g ha^{-1} during the 30-50% flowering period of the cherry trees. Trees that received no treatment were used as a control group. A total of 80 trees were studied at each site, 64 trees as treatment + 16 trees as control. As there is no other PGR registered for cherry, a second PGR control group was not used as a control. GroCel doses were calculated based on the amount of active ingredient (15% AVG) of the commercial formulation used. Treatments were carried out by spraying all predetermined healthy trees with a sprayer. The pH of the solutions prepared for the applications was measured to be 7 and the applications were made early in the morning. The amount of PGR + water per tree and the application dates are given in Table 1.

2.4. Measurements and evaluations

On branches where flowers were counted, small fruits and fruits set after June fall were counted, and fruit set (%) and harvest maturity date were determined according to cultivar-specific criteria. Yield per tree (kg $tree^{-1}$) and fruit quality analysis [(50 fruits per replicate, fruit width (mm), length (mm), fruit weight (g), kernel weight (g), pedicel length (mm), thickness (mm), flesh firmness (N), SSC (%), titratable acidity (TA, %), pH, fruit colour (L*, a*, b*, C*, h°)] were measured. Phytotoxicity and side effects of these treatments were also observed macroscopically. To determine the phytotoxic effects of PGR treatments on leaves, shoots and fruits, macroscopic observations were made on shoots, leaves and fruits a few days after application and until the dormant season. The effect of treatments on bee activity was also observed.

2.5. Statistical evaluation

Analysis of variance technique was used to evaluate the data obtained. Results were subjected to analysis of variance using JMP-7 package program and differences between means were determined according to LSD multiple comparison test ($P<0.05$).

3. Results

3.1. Research site characteristics and climate conditions

The soil analysis of the Eğirdir research orchard reveals a clayey texture with light alkaline pH (7.9) and medium lime content (8.19%). The soil is salt-free with moderate levels of essential macro and micronutrients, including phosphorus (72 ppm), potassium (527 ppm), calcium (4590 ppm), and magnesium (1287 ppm). Micronutrient concentrations, including iron (35.7 ppm), copper (18.3 ppm), manganese (10 ppm), and zinc (2.1 ppm), are present in moderate to sufficient quantities. Organic matter content (2.77%) is at medium levels (Table 2). On the other hand, the soil analysis of the Akşehir research orchard indicates a clayey texture with a lightly alkaline pH (8.1) and medium lime content (13.11%). The soil is salt-free with good organic matter content (3.35%). Macronutrient levels of phosphorus (101 ppm), potassium (297 ppm), and calcium (4074 ppm) are excessive, while magnesium (467 ppm) is at medium levels. Micronutrient analysis shows sufficient iron (10.6 ppm) and zinc (2 ppm), excessive copper (4.7 ppm), and medium manganese (3.8 ppm) concentrations (Table 3). The climate data revealed notable fluctuations in climatic conditions during the cherry flowering period across both research locations (Figure 1). At

Table 1. Amount of PGR + water per tree and application dates.

Location	Application date (%30-%50 blossom)		Application (g ha^{-1})	Amount of PGR per tree (g)	Amount of water used per tree (L)
	2023	2024			
Eğirdir	24 April	15 April	830	4.16	5
			700	3.12	5
			550	3.30	5
			400	1.62	5
Akşehir	18 April	15 April	830	4.16	5
			700	3.12	5
			550	3.30	5
			400	1.62	5

Table 2. Soil analysis results of the research orchard in Eğirdir location.

Analysis name	Results	Evaluation
Saturation (%)	89.1	Clayey
Salinity (Saturation Mud (mmhos cm^{-1})	0.023	Salt-free
pH (Saturation Mud)	7.9	Light alkaline
Lime (Calcimetric) (%)	8.19	Medium
Organic Matter (Smith Weldon) (%)	2.77	Medium
Phosphorus (Olsen-ICP) (ppm)	72.0	Moderate
Potassium (A. Acetate-ICP) (ppm)	527.0	Moderate
Calcium (A. Acetate-ICP) (ppm)	4590.0	Moderate
Magnesium (A. Acetate-ICP) (ppm)	1287.0	Moderate
Iron (DTPA-ICP) (ppm)	35.7	Moderate
Copper (DTPA-ICP) (ppm)	18.3	Moderate
Manganese (DTPA-ICP) (ppm)	10.0	Enough
Zinc (DTPA-ICP) (ppm)	2.1	Moderate

Table 3. Soil analysis results of the research orchard in Akşehir location

Analysis name	Results	Evaluation
Saturation (%)	71.5	Clayey
Salinity (Saturation Mud (mmhos cm^{-1})	0.012	Salt-free
pH (Saturation Mud)	8.1	Lightly alkaline
Lime (Calcimetric) (%)	13.11	Medium
Organic Matter (Smith Weldon) (%)	3.35	Good
Phosphorus (Olsen-ICP) (ppm)	101.0	Too much
Potassium (A. Acetate-ICP) (ppm)	297.0	Too much
Calcium (A. Acetate-ICP) (ppm)	4074.0	Too much
Magnesium (A. Acetate-ICP) (ppm)	467.0	Medium
Iron (DTPA-ICP) (ppm)	10.6	Enough
Copper (DTPA-ICP) (ppm)	4.7	Too much
Manganese (DTPA-ICP) (ppm)	3.8	Medium
Zinc (DTPA-ICP) (ppm)	2.0	Enough

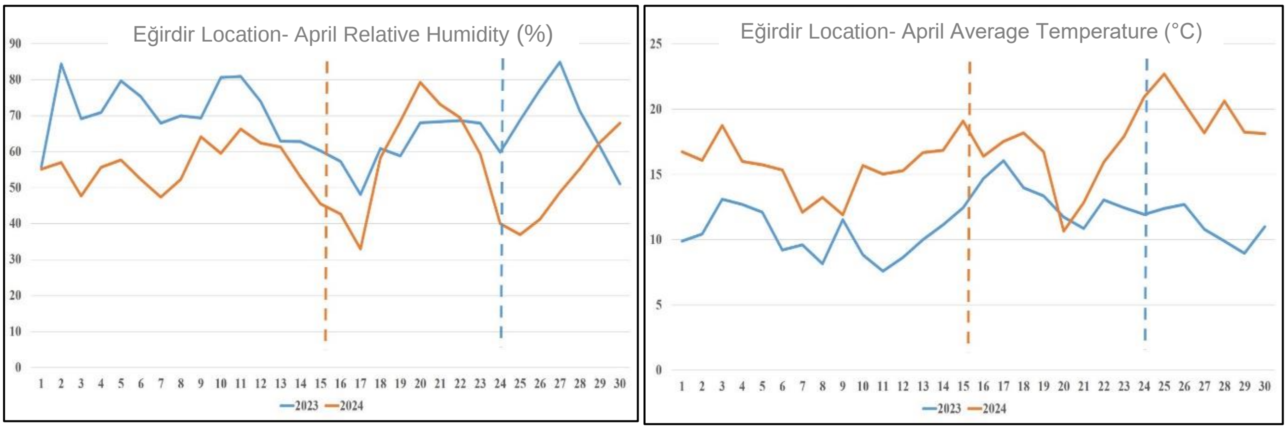

Figure 1. Relative humidity and average temperature data during flowering time for Eğirdir location in 2023-2024 (Anonymous, 2024).

the Eğirdir location, relative humidity fluctuated considerably between approximately 30-85%, while average daily temperatures ranged from 7°C to 23°C throughout April 2023-2024. These variations created distinct microclimatic conditions during critical pollination phases. Similarly, the Akşehir location experienced significant climate variability with relative humidity ranging from 20-90% and temperatures oscillating between 5°C and 24°C throughout the same period (Figure 2). Both locations demonstrated pronounced day-to-day climate fluctuations that could potentially impact flower viability, pollen tube growth, and subsequent fruit set in the studied cherry orchards. Between March 1 and July 31, a comparative analysis of climate data from Eğirdir and Akşehir revealed notable interannual variations (Table 4).

In Eğirdir, the year 2024 showed an increase in average temperature (from 16.33°C to 19.01°C), maximum temperature (from 21.73°C to 25.18°C), and minimum temperature (from 11.07°C to 12.99°C), while the average relative humidity decreased from 65.70% to 57.06%. Similarly, in Akşehir, average temperature rose from 14.96°C in 2023 to 17.60°C in 2024, with corresponding increases in maximum and minimum temperatures (from 20.89°C to 24.60°C and from 9.36°C to 11.14°C, respectively), whereas average relative humidity declined from 61.17% to 51.70%. Regarding total precipitation, both locations

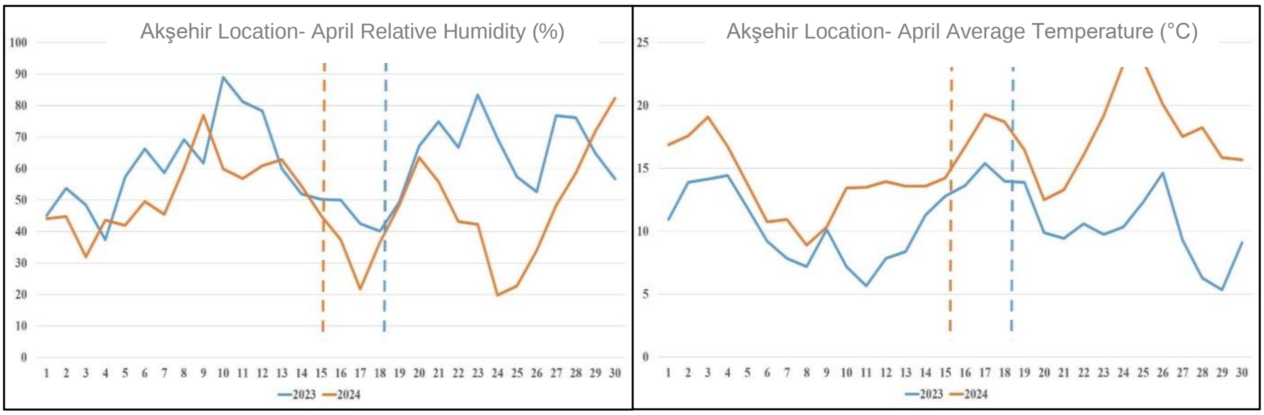

Figure 2. Relative humidity and average temperature data during flowering time for Akşehir location in 2023-2024 (Anonymous, 2024).

Table 4. Average relative humidity (%), average temperature, average maximum (max.) and average minimum (min.) temperature data between March 1 and July 31 (locations, 2023-2024) (Anonymous, 2024).

Location	Months	2023				2024			
		Relative humidity (%)	Temperature (°C)	Max. Temp. (°C)	Min. Temp. (°C)	Relative humidity (%)	Temperature (°C)	Max. Temp. (°C)	Min. Temp. (°C)
Eğirdir	March	70.27	9.04	13.86	4.89	63.59	9.59	14.83	4.75
	April	67.91	11.05	16.03	6.64	55.81	16.62	22.72	10.63
	May	71.16	15.75	21.28	10.69	61.96	17.09	23.14	11.50
	June	68.77	20.09	25.75	14.68	48.13	25.86	33.16	18.12
	July	50.69	25.44	31.55	18.35	55.66	25.95	32.19	19.98
	Average	65.70	16.33	21.73	11.07	57.06	19.01	25.18	12.99
Akşehir	March	65.21	7.96	13.13	3.11	60.53	8.13	14.53	2.87
	April	61.27	10.30	15.88	5.39	48.87	15.66	22.49	9.11
	May	69.84	14.15	19.74	9.05	63.05	14.99	21.87	9.13
	June	68.61	18.38	24.31	12.91	39.00	24.65	32.37	16.50
	July	41.31	23.76	31.10	16.13	46.55	24.74	31.94	18.21
	Average	61.17	14.96	20.89	9.36	51.70	17.60	24.60	11.14

experienced a substantial decrease in 2024. In Eğirdir, cumulative precipitation dropped from 467.40 mm in 2023 to 242.80 mm in 2024. Likewise, Akşehir recorded a decline from 332.20 mm to 164.20 mm over the same period (Table 5).

3.2. Effects of applications on fruit set, yield and physical properties

In 2023 and 2024, varying doses of the tested application (400, 550, 700, and 830 g ha^{-1}) had significant effects on fruit set and yield in both Eğirdir and Akşehir. In Eğirdir, the highest fruit set in 2024 was observed at 830 g ha^{-1} (4.80%), which represented a 147% increase compared to the control (1.94%). Yield followed a similar pattern, reaching 6.08 kg tree^{-1} at 830 g ha^{-1}, a 220% increase relative to the control (1.90 kg tree^{-1}). These differences were statistically significant (*P<0.05*) (Table 6). In Akşehir, the impact of applications was even more pronounced. The 830 g ha^{-1} dose resulted in the highest fruit set (41.25%) and yield (11.91 kg tree^{-1}) in 2024, representing increases of over 600% in fruit set and over 110% in yield compared to the control treatment (5.58% fruit set and 5.58 kg yield). Statistically significant differences were observed across all application levels for both parameters in both years (*P<0.05*), indicating a clear positive dose-dependent response (Table 6).

In Eğirdir, none of the treatments (control) significantly influenced the physical properties of fruits in either year (*P>0.05*) for all parameters. Although there were numerical increases in some parameters, such as fruit weight and length, these differences were not statistically meaningful. For instance, in 2024, the fruit weight increased from 8.32 g (control) to 8.60 g at 550 g ha^{-1}, and fruit length ranged from 23.1 mm to 24.6 mm across treatments. However, variability was insufficient to establish significant treatment effects. In contrast, Akşehir showed more pronounced and statistically significant responses to treatments, particularly in 2023. Fruit weight, width, and length were significantly affected by the treatments (*P<0.05*). The control group had the highest fruit weight (10.49 g), but it was not statistically different from the 400 g ha^{-1} dose (10.23 g), while the lowest value was observed at 830 g ha^{-1} (8.63 g). Fruit width in the control was also highest (28.1 mm), followed closely by 400 g ha^{-1} (27.8 mm). Notably, fruit length was significantly higher in the control and 400 g ha^{-1} (25.5 mm and 25.3 mm, respectively), whereas the lowest value was recorded in the 830 g ha^{-1} treatment (23.7 mm). Seed weight was not significantly affected by any of the treatments in

Table 5. Total precipitation between March 1 and July 31 (Location, 2023-2024) (Anonymous, 2024).

Location	Month	Total precipitation (mm)	
		2023	2024
Eğirdir	March	170.80	42.20
	April	129.80	54.60
	May	57.60	68.20
	June	109.00	48.20
	July	0.20	29.60
	Total	467.40	242.80
Akşehir	March	105.40	33.80
	April	55.80	27.60
	May	62.60	73.60
	June	107.80	7.80
	July	0.60	21.40
	Total	332.20	164.20

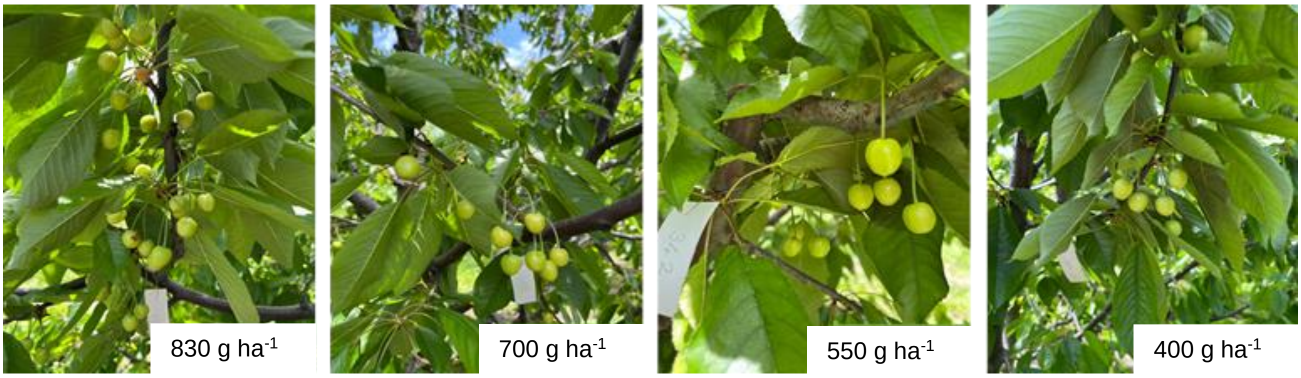

Figure 3. Fruit set images of GroCel applications

Table 6. Effect of applications on fruit set (%) and yield (kg tree^{-1}).

Location	Applications (g ha^{-1})	Fruit set		Yield	
		2023	2024	2023	2024
Eğirdir	Control	29.75	1.94 c*	18.54 c*	1.90 c*
	830	36.65	4.80 a	35.39 ab	6.08 a
	700	36.36	3.54 ac	35.35 ab	4.69 b
	550	29.91	3.15 bc	36.76 a	4.52 b
	400	29.02	4.05 ab	28.76 b	4.49 b
	P value	0.2453	0.0260	0.0012	<.0001
Akşehir	Control	3.15 b*	12.50 c*	2.26 b*	5.58 c*
	830	18.66 a	41.25 a	4.93 a	11.91 a
	700	17.95 a	41.00 a	2.81 ab	7.37 bc
	550	14.97 a	29.50 b	4.78 a	10.67 ab
	400	4.97 b	22.75 b	4.70 a	10.75 ab
	P value	0.0007	0.0002	0.0486	0.0317

*Differences between means shown with different letters in the same column are statistically significant (*P<0.05*).

either location or year (*P>0.05*). Overall, while applications had limited effect on fruit physical properties in Eğirdir, moderate and significant changes were observed in Akşehir, particularly in the 2023 season (Table 7).

In our result for 2023, the application of 550 g ha^{-1} at Eğirdir significantly increased stem length (48.3 mm) compared to the control (45.9 mm), representing a 5.2% increase (*P* = 0.0081). However, no significant differences were observed among treatments in stem thickness, stem weight, or stem length in 2024 (*P>0.05*). Flesh firmness in 2023 was the highest in the control group (12.25 N), while the lowest value was observed in the 400 g ha^{-1} treatment (11.24 N), with a 8.2% decrease (*P* = 0.0154). At Akşehir, the control treatment resulted in the highest stem length (54.5 mm) in 2023, which was significantly reduced by the 830 g ha^{-1} and 700 g ha^{-1} treatments by 8.2% and 6.7%, respectively (*P* = 0.0082). In 2024, stem length and stem thickness were also significantly affected (*P* = 0.0008 and p = 0.0001, respectively), with the 400 g ha^{-1} treatment maintaining relatively high stem length (41.8 mm) and stem thickness (1.0 mm). Stem weight was significantly higher in the control group in both years (*P<0.05*). Flesh firmness was significantly improved in 2024 by the 400 g ha^{-1} application (14.33 N), showing a 46.9% increase compared to 2023 values (9.75 N) (*P* = 0.0182), while the control treatment maintained the highest firmness in 2023 (9.96 N) (*P* = 0.0148) (Table 8).

Table 7. Effect of treatments on some physical properties of fruits.

Location	Applications (g ha^{-1})	Fruit weight (g)		Fruit width (mm)		Fruit length (mm)		Seed weight (g)	
		2023	2024	2023	2024	2023	2024	2023	2024
Eğirdir	Control	7.22	8.32	23.7	25.8	22.3	23.7	0.41	0.43
	830	6.54	7.84	22.4	25.1	21.2	23.7	0.41	0.45
	700	7.17	7.91	23.7	25.4	21.9	23.5	0.39	0.41
	550	6.72	8.60	22.8	26.3	21.6	24.6	0.37	0.43
	400	6.55	7.13	22.9	24.2	21.5	23.1	0.39	0.39
	P value	0.2889	0.1226	0.1224	0.0869	0.2298	0.2176	0.0710	0.2534
Akşehir	Control	10.49 a*	7.53	28.1 a*	24.8	25.5 a*	22.7	0.40	0.37
	830	8.63 b	7.80	26.0 b	25.2	23.7 b	23.1	0.41	0.33
	700	8.93 b	7.81	26.3 b	25.2	24.0 b	22.9	0.40	0.33
	550	9.17 b	7.71	26.4 b	25.0	24.2 b	22.7	0.41	0.35
	400	10.23 a	7.40	27.8 a	24.5	25.3 a	22.4	0.40	0.35
	P value	0.0018	0.2751	0.0017	0.1315	0.0004	0.2172	0.9145	0.1060

*Differences between means shown with different letters in the same column are statistically significant (P<0.05).

Table 8. Effects of applications on some fruit stem characteristics and fruit flesh firmness in fruits.

Location	Applications (g ha^{-1})	Stem length (mm)		Stem thickness (mm)		Stem weight (g)		Flesh firmness (N)	
		2023	2024	2023	2024	2023	2024	2023	2024
Eğirdir	Control	45.9 b*	42.5	1.8	1.2	0.15	0.12	12.25a*	12.23
	830	43.4 c	42.2	1.3	1.0	0.13	0.11	11.62bc	13.09
	700	44.9 bc	42.1	1.6	1.1	0.13	0.11	11.89ab	13.19
	550	48.3 a	43.6	1.0	1.4	0.14	0.12	12.09ab	12.30
	400	45.1 bc	43.0	1.6	1.0	0.13	0.10	11.24c	12.82
	P value	0.0081	0.7104	0.6281	0.2995	0.0937	0.0620	0.0154	0.2847
Akşehir	Control	54.5 a*	42.9 a*	1.0 a*	0.9	0.13 a*	0.12 a*	9.96 a*	13.79 a*
	830	50.0 b	36.3 d	0.8 b	1.0	0.10 c	0.09 b	9.38 ab	13.59 a
	700	50.8 b	37.3 cd	0.9 b	1.0	0.10 c	0.09 b	9.10 b	12.14 b
	550	54.3 a	39.5 bc	1.0 a	0.9	0.12 b	0.10 ab	8.89 b	13.42 a
	400	55.0 a	41.8 ab	1.0 a	0.9	0.14 a	0.11 a	9.95 a	14.33 a
	P value	0.0082	0.0008	0.0001	0.1450	<.0001	0.0280	0.0148	0.0182

*Differences between means shown with different letters in the same column are statistically significant ($P<0.05$).

3.3. Chemical properties and safety of applications

In both locations and across both years, the applications did not result in statistically significant differences in fruit color parameters (Table 9 and 10), including L*, a*, b*, C* (chroma), and h° (hue angle) ($P>0.05$). At Eğirdir, L* values ranged from 36.21 to 37.82 in 2023 and from 31.61 to 33.69 in 2024. The highest a* value (35.58) was observed in the 830 g ha^{-1} treatment in 2023, corresponding to a 4.5% increase compared to the control. In terms of b*, the 700 g ha^{-1} treatment yielded the highest value in 2024 (12.72), indicating a 2.6% increase over the control. C* values in Eğirdir ranged from 37.75 to 39.20 in 2023 and from 26.94 to 30.95 in 2024, with the 830 g ha^{-1} application showing a 3.2% increase over the control in 2023. However, these differences were not statistically significant. Similarly, h° values were highest in the control group in both years but did not differ significantly among treatments. At Akşehir, L*, a*, and b* values also did not vary significantly between treatments. In 2024, the 400 g ha^{-1} treatment produced the highest a* (26.88) and b* (12.64) values, reflecting increases of 10.0% and 10.7%, respectively, compared to the control. C* values at this location were generally lower than those in Eğirdir, with the highest value again observed in the 400 g ha^{-1} treatment in 2024 (30.93), indicating a 19.4% increase over the 2023 control (25.92). Hue angle (h°) also showed slight numerical increases, particularly in the 400 g ha^{-1} group (23.49 in 2024), yet none of these changes reached statistical significance.

On the other hand, according to our research findings, the effects of different application doses on the chemical properties of fruits varied by location and year. When examining SSC values, control applications generally showed the highest values in both 2023 and 2024 at both Eğirdir and Akşehir locations. In terms of pH values, no statistically significant difference was observed in 2023, while significant differences ($P<0.0001$) were detected in 2024, especially in Eğirdir. No significant differences were observed in TA values in Eğirdir in both years, however, statistically significant differences (P = 0.0362) emerged between application doses in Akşehir in 2024. Notably, the 830 g ha^{-1} dose provided the highest TA value in Akşehir in 2024 (Table 11). On the other side, macroscopic observations on shoots, leaves and fruits at all locations followed a few days after the application and until the rest of the season showed no phytotoxicity or side effects of GroCel (15% AVG, ReTain) treatments. It was also determined that the treatments had no negative effect on bee activity.

Table 9. Effect of applications on color formation in fruits (L*, a*, b*).

Location	Applications (g ha^{-1})	L*		a*		b*	
		2023	2024	2023	2024	2023	2024
Eğirdir	Control	37.82	33.21	34.05	27.40	16.62	12.40
	830	36.57	32.94	35.58	26.62	16.35	11.42
	700	36.21	33.69	34.32	28.15	15.59	12.72
	550	37.31	32.59	35.13	25.56	16.50	10.74
	400	36.83	31.61	35.29	24.78	16.32	10.48
	P value	0.3819	0.1680	0.4132	0.2599	0.8651	0.2604
Akşehir	Control	31.14	31.18	24.44	26.59	8.47	11.42
	830	30.03	30.94	22.61	25.35	7.71	10.60
	700	31.18	30.53	24.70	23.54	8.12	9.68
	550	30.40	31.30	24.62	26.95	8.18	11.75
	400	32.10	31.93	26.88	28.19	10.21	12.64
	P value	0.1135	0.5585	0.0663	0.1811	0.1412	0.1885

Table 10. Effect of applications on color formation in fruits (C*: Chroma, h°: Hue angle)

Location	Applications (g ha^{-1})	C*		h°	
		2023	2024	2023	2024
Eğirdir	Control	37.99	30.12	25.37	23.69
	830	39.20	29.00	24.48	22.76
	700	37.75	30.95	24.09	23.58
	550	38.86	27.75	24.87	22.45
	400	38.95	26.94	24.52	22.37
	P value	0.7170	0.2591	0.6838	0.3577
Akşehir	Control	25.92	28.97	18.25	22.68
	830	23.36	27.49	16.84	22.35
	700	26.03	25.47	17.69	21.94
	550	25.87	29.43	17.76	23.08
	400	26.82	30.93	18.86	23.49
	P value	0.1348	0.1794	0.1157	0.3528

Table 11. Effects of applications on some chemical properties of fruits.

Location	Applications (g ha^{-1})	SSC (%)		pH		TA (%)	
		2023	2024	2023	2024	2023	2024
Eğirdir	Control	15.60a*	18.73a*	3.60	3.04c*	0.69	1.08
	830	14.55b	17.20a	3.56	3.27a	0.75	1.06
	700	14.68ab	13.25b	3.54	3.32a	0.74	1.00
	550	14.15b	18.08a	3.49	3.19b	0.79	0.98
	400	14.00b	18.75a	3.60	3.06c	0.73	1.04
	P value	0.0217	0.0162	0.8128	<.0001	0.2169	0.7665
Akşehir	Control	17.03a*	18.55a*	3.53	3.07	0.73	1.50a*
	830	15.20c	18.03ab	3.53	3.12	0.55	1.56a
	700	15.65bc	18.58a	3.57	3.15	0.40	1.37ab
	550	15.30c	17.03bc	3.57	3.18	0.36	1.14b
	400	16.55ab	16.85c	3.32	3.12	0.53	1.34ab
	P value	0.0033	0.0130	0.8737	0.0527	0.0514	0.0362

SSC: Soluble solids content, TA: Titratable acidity, *Differences between means shown with different letters in the same column are statistically significant (*P<0.05*).

4. Discussion

4.1. Impact of climate conditions on cherry fruit set and AVG efficacy

The pronounced variability in fruit set observed between the 2023 and 2024 growing seasons at the Eğirdir location demonstrated the critical influence of microclimate on reproductive success in cherry trees. In 2024, fruit set was substantially lower compared to 2023, coinciding with dramatic temperature fluctuations during the critical period between 30% flowering and the end of flowering. Specifically, the rapid temperature increase from 18-19°C on April 15 to 22-23°C on April 23-24 (Figure 3) appears to have significantly compromised reproductive success. This finding strongly corroborates the work of Sarısu (2017), who established that elevated temperatures during flowering negatively affect fruit yield in the '0900 Ziraat' cherry cultivar. The physiological explanation for this temperature sensitivity lies in the accelerated aging of ovule tissue at higher temperatures, a relationship well-documented by Postweiler et al. (1985), who reported that while cherry and sour cherry ovules remained viable for up to 5 days after anthesis at 5°C, this viability period shrank dramatically to merely 1-2 days at 20°C. Our observations align remarkably well with controlled pollination studies by Beppu et al. (1997), who documented a non-linear response to temperature in cherry fruit set, with optimal results at moderate temperatures (50% at 15°C) and sharp declines at higher temperatures (just 2% at 25°C). The temperature patterns recorded at our research sites during the critical flowering and fertilization periods offer a compelling explanation for the year-to-year variation in control treatment fruit set. At Eğirdir, the distinctly lower fruit set in 2024 coincided with temperature instability that likely shortened ovule longevity and disrupted pollen tube growth dynamics, whereas the more favorable temperature regime at Akşehir in 2024 supported higher baseline fruit set even in control trees.

The application of GroCel (15% AVG) demonstrated a remarkable capacity to counteract these adverse temperature effects, with treated trees maintaining significantly enhanced fruit set despite challenging environmental conditions. This protective effect was particularly pronounced at Eğirdir in 2024, where despite unfavorable temperature patterns, trees receiving the highest application rate (830 g ha^{-1}) achieved a 147% increase in fruit set compared to controls (4.80% versus 1.94%). The physiological basis for this protective effect likely involves AVG's inhibition of ethylene biosynthesis, which may delay senescence in floral tissues and extend the effective pollination period. Under normal conditions, ethylene levels increase in response to temperature stress and accelerate flower and ovule senescence, limiting the window for successful fertilization (Sabir et al., 2021). The dose-dependent response observed across both locations further strengthens the evidence for AVG's efficacy in enhancing reproductive success. At Akşehir, the impact was even more dramatic, with the 830 g ha^{-1} dose resulting in fruit set of 41.25% in 2024, representing a more than 600% increase over the control treatment (5.58%). These results substantially exceed the improvements reported by Bound et al. (2013) in Tasmanian conditions (55% increase in 'Kordia' and 33% in 'Regina'), suggesting that AVG application may be particularly beneficial for '0900 Ziraat' under Mediterranean climate conditions. The consistent improvement across both research locations and growing seasons, despite their distinct soil properties and microclimatic conditions, further validates the robustness of AVG's positive effect on fruit set in cherry orchards. The climate data analysis reveals an interesting pattern regarding the interannual variations between 2023 and 2024. Both locations experienced higher average temperatures and lower relative humidity in 2024, along with substantially reduced precipitation (from 467.40 mm to 242.80 mm in Eğirdir and from 332.20 mm to 164.20 mm in Akşehir). These broader seasonal climate differences likely contributed to the observed variation in fruit set responses, aligning with research by ShiPing et al. (2004) and Beppu and Kataoka (2011) regarding the complex interplay between temperature, moisture availability, and reproductive success in *Prunus* species.

4.2. Effects of AVG on fruit physical and chemical properties

The differential impact of GroCel applications on fruit physical properties between the two research locations provided valuable insights into the potential interaction between AVG treatment and environmental conditions. At Eğirdir, fruit physical parameters remained largely unaffected by AVG application, with no statistically significant differences observed in fruit weight, length, width, or seed weight across treatments in either year. This stability suggests that under the specific soil and climate conditions at Eğirdir, the physiological pathways governing fruit expansion and development were not substantially altered by ethylene inhibition during the flowering period. In contrast, at Akşehir, AVG applications produced significant effects on fruit physical characteristics, particularly in 2023, when fruit weight, width, and length all showed statistically significant responses to treatment ($P<0.05$). The inverse relationship between application rate and fruit size was evident, with the control group exhibiting the highest fruit weight (10.49 g) and the 830 g ha^{-1} treatment yielding the lowest (8.63 g). This pattern aligns with findings by Bound et al. (2013), who reported decreased fruit diameter in AVG-treated 'Kordia' cherries. The physiological explanation for this effect likely involves resource allocation dynamics within the tree. With significantly increased fruit set in AVG-treated trees, the available carbohydrates and nutrients must be distributed among a larger number of developing fruits, potentially resulting in smaller individual fruit size. The more pronounced effect at Akşehir may be related to the greater magnitude of fruit set increase achieved at this location, which would intensify competition among developing fruits.

The analysis of stem characteristics revealed interesting temporal and location-dependent patterns. At Eğirdir in 2023, the 550 g ha^{-1} application significantly increased stem length compared to the control (48.3 mm versus 45.9 mm), while at Akşehir, control treatments maintained the highest stem length and weight across both years. These findings suggest that AVG may influence carbon partitioning between fruits and accessory structures, with higher application rates potentially directing more resources toward fruit development at the expense of stem growth. The significant improvement in flesh firmness observed with the 400 g ha^{-1} application at Akşehir in 2024 (14.33 N, representing a 46.9% increase compared to 2023) indicates that moderate AVG application may enhance certain quality parameters even while others are slightly reduced.

Regarding fruit color parameters, the absence of statistically significant differences across treatments for L*, a*, b*, C*, and h° values at both locations and across both years confirms that AVG application does not disrupt normal pigment development in cherry fruits. This stability is particularly important from a commercial perspective, as fruit color represents a primary quality attribute for consumer acceptance. The slight numerical increases observed in some color parameters with AVG treatment, such as the 4.5% increase in a* value (redness) with 830 g ha^{-1} application at Eğirdir in 2023, suggest that ethylene inhibition during flowering does not negatively impact subsequent anthocyanin accumulation during ripening. This finding is consistent with Bound et al. (2013), who reported no significant effect of AVG on fruit color in either 'Kordia' or 'Regina' cultivars. The chemical property analysis revealed that control applications generally produced the highest soluble solids content (SSC) values at both locations across both years, indicating that AVG application may slightly reduce sugar accumulation in cherry fruits. This finding corresponds with Ağlar et al. (2014), who reported significant decreases in SSC in AVG-treated '0900 Ziraat' cherries. The physiological basis for this effect may involve altered sink strength or carbon partitioning patterns resulting from ethylene inhibition during early fruit development. The significantly higher TA observed with the 830 g ha^{-1} dose at Akşehir in 2024 suggests that AVG may differentially affect sugar and acid metabolism pathways. The significant pH differences detected in 2024, particularly at Eğirdir ($P<0.0001$), further support the notion that AVG influences fruit acid metabolism, though these effects appear to be modulated by seasonal and location-specific factors.

4.3. Physiological mechanisms and practical implications of AVG application

The consistent enhancement of fruit set and yield across both research locations and growing seasons provides compelling evidence for the efficacy of AVG as a management tool in cherry production. The physiological mechanism underlying these benefits likely involves multiple pathways related to ethylene inhibition during critical reproductive phases. Under normal conditions, ethylene functions as a senescence hormone that accelerates flower aging and potentially compromises ovule longevity (Sabir et al., 2021). In cherry flowers, ethylene production increases rapidly after pollination and during periods of environmental stress, potentially shortening the effective pollination period, especially under adverse temperature conditions. AVG functions by inhibiting 1-aminocyclopropane-1-carboxylic acid (ACC) synthase, the rate-limiting enzyme in ethylene biosynthesis that catalyzes the conversion of S-adenosylmethionine (SAM) to ACC (Ağlar et al., 2014). By blocking this crucial step, AVG reduces ethylene production in floral tissues, potentially extending ovule viability and prolonging the effective pollination period. This mechanism is particularly relevant for '0900 Ziraat' cherry, which frequently experiences pollination challenges including rapid ovule senescence, variable pollen viability, and asynchronous flowering with pollinizer varieties (Sarısu and Aşkın, 2014). The dose-dependent response observed in our study suggests that higher AVG concentrations provide more complete inhibition of ethylene biosynthesis, resulting in greater fruit set enhancement. The optimal performance of the highest dose tested (830 g ha^{-1}) indicates that this application rate effectively balances ethylene inhibition with other physiological processes without inducing phytotoxicity or disrupting pollinator activity. The remarkable yield increases achieved with this application rate (220% at Eğirdir and over 110% at Akşehir relative to controls) demonstrate the substantial commercial potential of this management approach.

The trade-off between increased yield and slightly reduced fruit size presents an important consideration for orchard management decisions. At Akşehir, where fruit weight and diameter decreased significantly with AVG treatment, growers must weigh the benefits of substantially higher fruit numbers against the potential reduction in individual fruit size. However, the magnitude of yield improvement (from 5.58 kg $tree^{-1}$ to 11.91 kg $tree^{-1}$ at Akşehir with 830 g ha^{-1} application in 2024) likely outweighs the modest size reduction from an economic perspective. Additionally, the absence of significant negative effects on other quality parameters such as flesh firmness and color further support the commercial viability of AVG application. The finding that AVG application did not induce phytotoxicity or disrupt bee activity is particularly significant for practical implementation. This safety profile aligns with previous research on AVG applications in cherry production (Ağlar et al., 2014; Bound et al., 2013) and indicates that GroCel can be integrated into existing orchard management practices without disrupting ecological relationships or compromising tree health. This aspect is crucial for sustainable orchard management, as any negative impacts on pollinators could potentially undermine the fruit set benefits achieved through chemical application. For the '0900 Ziraat' cherry variety, which is valued for export but often experiences yield fluctuations (Aşkın and Sarısu, 2020), the stabilizing effect of AVG application on year-to-year productivity represents a significant advancement. By mitigating the impact of adverse environmental conditions during flowering, particularly temperature fluctuations that compromise ovule longevity, AVG application offers a practical solution to one of the most persistent challenges in cherry production. The consistency of positive results across different soil types (clayey with light alkaline pH at both locations, but with different nutrient profiles) further demonstrates the robustness of this approach across varying growing conditions.

4. Conclusion

Our research evaluated the effects of GroCel (15% AVG, ReTain) applications on '0900 Ziraat' cherry trees across two locations during the 2023-2024 growing seasons. Application timing (30-50% flowering period) and dose rate significantly influenced fruit set and yield in both locations, with the highest application rate consistently demonstrating superior performance at both Eğirdir and Akşehir research orchards. Effects on fruit quality parameters varied by location and season. At Eğirdir, physical fruit properties remained largely unaffected across treatments, while Akşehir showed decreases in fruit weight and size with increasing AVG doses. Chemical properties showed modest changes, with control treatments generally exhibiting higher soluble solids content. Importantly, fruit color parameters were not significantly affected by AVG application at either location, or no phytotoxicity or adverse effects on pollinator activity were observed. Climate conditions significantly influenced treatment efficacy, with the protective effect of AVG against temperature fluctuations particularly evident at Eğirdir in 2024, where rapid temperature shifts during flowering compromised fruit set in untreated trees. The ethylene-inhibiting action of AVG likely extended ovule longevity during these adverse conditions, enabling successful fertilization despite environmental challenges. We conclude that GroCel application at the highest tested dose during the 30-50% flowering period represents an effective management strategy for stabilizing '0900 Ziraat' cherry production, particularly in regions experiencing climate variability. The substantial yield benefits outweigh modest reductions in fruit size and soluble solids content, making this approach commercially valuable for this export-oriented cherry cultivar. Future research should investigate the interaction between AVG application and various pollinizer varieties, as well as explore potential synergistic effects with other plant growth regulators to further optimize reproductive success in cherry orchards under changing climatic conditions.

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