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Modulatory Effects of Mepiquat Chloride on Physiological, Agronomic, and Fiber Quality Parameters of Cotton (*Gossypium hirsutum* L.) under Varying Application Timings

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Abstract

Background A two-year field experiment elucidates the interactive effects of genotype and Mepiquat Chloride (MC) management to enhance cotton growth and productivity using a split–split–plot design. Plant growth regulators (PGRs) play a pivotal role in modulating physiological processes, thereby enhancing plant health, architecture, yield potential, and fiber quality. In this context, the study assessed the impact of foliar-applied MC at varying rates on two conventional cotton cultivars, Selin and Sezener. Mepiquat Chloride treatments were administered at key phenological stages: at squaring, 8 weeks after planting (WAP), and boll-setting (11 WAP) across two consecutive growing seasons to determine their effects on growth regulation, yield stability, and overall crop performance.

Results Significant genotype $\times$ environment $\times$ management interactions were observed in cotton growth, yield, and fiber quality responses MC application. Plant height was significantly affected by year $\times$ variety interaction ($p < 0.01$), with the tallest plants in Selin (2023) and Sezener (2022). Leaf area was higher in 2022, while 800 cc. ha⁻¹ enhanced leaf expansion. Monopodial branches were significantly greater in 2023 (9.59 plant⁻¹), with early MC application favoring branch initiation. Seed cotton yield was peak in Selin (3623 kg ha⁻¹), 25% greater than Sezener, with split application (400 + 400 cc. ha⁻¹) yielding best results. Boll number and individual fiber weight were higher in Selin and Sezener, respectively, with the latter showing a 48% increase under 400 cc. ha⁻¹. Seed index was significantly higher in Sezener, and fiber moisture increased in 2023 (8.94%). Fiber quality traits revealed pronounced year, genotype, and application timing effects: fiber length peaked in Sezener (30.33 mm), elongation reached 5.80%, and micronaire increased to 4.89 $\mu\text{g inch}^{-1}$ under split MC application. Fiber strength increased by 13.07% in 2023, and while uniformity (85.62%) maximized with later application. Short fiber content decreased by 14.81% in 2023.

Conclusions These findings highlight that MC concentration, timing, and genotype interactions significantly modulate morphophysiological traits, yield components, and fiber quality, with split

or moderate-dose applications enhancing productivity and fiber properties under Mediterranean conditions.

Keywords: Cotton, morphophysiological, Mepiquat Chloride, timing, quality traits, yield components

Background

Cotton (*Gossypium hirsutum* L.), a major cash crop of the Malvaceae family, is cultivated in more than 70 countries, particularly across tropical and subtropical regions (Mangi et al., 2024; Thavkar et al., 2025). It holds substantial industrial and commercial importance and serves as a vital and sustainable source of income and employment for millions of smallholder farmers worldwide (Çınar et al., 2023; Liu et al., 2023; Zhang et al., 2023). Its fibers contribute approximately 81% of the raw materials used in the global textile industry (Keller et al., 2024), while its seeds serve as a major source of edible oils and livestock feed (Damalas & Koutroubas, 2025; Zhu et al., 2023).

Despite substantial advancements in cotton production technologies, global productivity remains suboptimal due to the complex interplay of agronomic, climatic, environmental, socio-economic, and political factors (Tlatlaa et al., 2023b). Although cotton thrives in high-temperature environments—ideally between 40°C and 45°C—and is inherently suited for heat-prone regions (Zafar et al., 2021, 2022), its productivity is increasingly constrained by the intensifying impacts of climate change (Arekhi et al., 2023; Ullah et al., 2022). Major stressors such as erratic rainfall, prolonged drought, rising temperatures, and evolving pest and disease pressures have collectively disrupted the crop's growth cycles, physiological stability, and reproductive development (Amissah et al., 2023; Cinar et al., 2024; Zafar et al., 2023). These challenges are especially detrimental during sensitive phenological stages, ultimately leading to significant yield reductions and threatening the long-term sustainability of cotton-based farming systems (Khan et al., 2025; Zhang et al., 2024; Zhu et al., 2023).

In climate-stressed countries such as China, India, the United States, Brazil, Pakistan, and Turkey, early-maturing cotton varieties have been increasingly adopted as an adaptive strategy, owing to their shorter growth cycles and lower water requirements (Çelik, 2023). However,

while early-maturing genotypes offer advantages under water-limited and heat-stressed conditions, tend to exhibit excessive vegetative growth when environmental conditions are favorable, often at the expense of reproductive development (Beegum et al., 2023). This vegetative-reproductive imbalance leads to poor boll retention, delayed maturity, and ultimately reduced fiber yield and quality (Sreedasyam et al., 2024). Yield losses of 6–10% per 1 °C rise above optimal temperatures (~30–32 °C) have been reported, underscoring the urgency of developing adaptive strategies for sustaining productivity under warming conditions (Saini et al., 2023; Sharma et al., 2021).

One promising approach to mitigate heat-induced vegetative–reproductive imbalance is the use of plant growth regulators, particularly mepiquat chloride (MC), a quaternary ammonium (N, N-dimethylpiperidinium chloride) compound that inhibits gibberellin biosynthesis (Al-Khayri et al., 2024; Zhang et al., 2020). By restricting stem elongation, reducing node production, and promoting a more compact canopy architecture, MC can reallocate assimilates from vegetative to reproductive sinks (Chalise et al., 2022; Liang et al., 2020; Zhang et al., 2021). Numerous studies have demonstrated its ability to enhance boll retention, increase boll number and weight, and improve fiber quality under conventional production conditions (Meng et al., 2023; Shi et al., 2022; Zhao et al., 2017). However, its efficacy appears strongly influenced by genotype, dose, timing, and environmental conditions (Malima et al., 2025a; Wang et al., 2022).

Evidence from controlled-environment experiments shows that MC's growth-suppressing effects are temperature sensitive (Sabagh et al., 2022). At moderate day/night regimes (~32–35 °C), MC markedly reduces plant height, node number, and leaf expansion, while increasing fruit retention (Grundy et al., 2020; Reddy et al., 1990). Under more severe heat (≥ 39 °C), these effects diminish, and higher doses are required to maintain even partial growth control (Rosolem et al., 2013; Saini et al., 2023). Field studies in water-limited or high-radiation environments similarly report yield gains of 15–34% and improvements in boll retention and fiber traits (micronaire, strength, length, and uniformity) when MC is combined with nitrogen fertilization or applied at optimal growth stages (Abbas et al., 2022; Al-Khayri et al., 2024; Lee et al., 2023). Nevertheless, the magnitude of these benefits is inconsistent and tends to decline under intense heat stress (Hand et al., 2023; Luo et al., 2023; Reddy et al., 1996; Tung et al., 2018).

While MC shows potential as a tool for moderating heat-related yield losses, its ability to stabilize fiber quality under such conditions remains unclear. Most available data come from studies on mid- to late-maturing cultivars grown under non-stress conditions, with limited evidence from early-maturing genotypes commonly cultivated in the Mediterranean region of Turkey. Moreover, the dose $\times$ application timing $\times$ environmental conditions interaction governing MC effectiveness has not been systematically quantified, and the genetic variation in cotton responsiveness to MC under climate-stressed conditions is poorly understood.

Addressing these knowledge gaps is critical for developing climate-resilient cotton production systems. Specifically, there is a need to (i) define agro-meteorological thresholds beyond which MC loses efficacy, (ii) optimize its timing and dosage relative to concurrent heat + drought episodes, and (iii) evaluate genotypic differences in yield and fiber quality responses to MC under stress-prone field conditions. Such insights will enable the strategic integration of MC into adaptive management packages potentially in combination with adjusted sowing dates, irrigation scheduling, and canopy management practices to sustain cotton yield and fiber quality in the warming Mediterranean basin.

Materials and methods

Description of the Study Site

The experiment took place during the 2022 and 2023 cropping years at the Eastern Mediterranean Agricultural Research Institute, situated at Adana/Turkey (at coordinates 36°51' N latitude and 35°20' E longitude). During summer, the Mediterranean region is characterized by warm and mild conditions, with mean monthly temperatures ranging from 20.30 to 30.49 °C. Average monthly rainfall during this period varies between 2.20 mm and 41.20 mm, while relative humidity ranges from 40.95% to 54.95% (Kızılsımsek et al., 2024).

Soil Characteristics of the Study Site

Soil samples were collected from the 0–30 cm profile at the experimental site, and their characteristics were analyzed using air-dried fine earth fractions. Particle size distribution was determined following the method described by Gee & Or, (2018). Soil pH (H₂O) was measured

according to Mclean, (1982), while organic carbon content was determined using the Walkley–Black wet combustion method (Nelson & Sommers, 2018). Phosphorus was analyzed following the procedure of Olsen & Sommers LE, (1982), while calcium (Ca) and potassium (K) contents were determined using an atomic absorption spectrophotometer as described by Thomas, (1982). The soil characteristics of the experimental site are presented in Table 1.

Experimental Design and Treatments

A sample layout of a 2 x 2 x 4 factorial experiment arranged in a split-split-plot design with two cultivars (C_1 and C_2) as main-plot treatments, two spraying intervals (T_1 and T_2) as subplot treatments, and four Mepiquat Chloride (MC) levels (MC_0 , MC_1 , MC_2 and MC_3) as sub-subplot treatments, in three replications. MC treatments used in this study were MC_0 (0 cc. ha^{-1}), MC_1 (400 cc. ha^{-1}), MC_2 (400 + 400 cc. ha^{-1}) and MC_3 (800 cc. ha^{-1}). The cotton cultivars entailed of Selin and Sezener, both of which are early-maturing. The growth regulator and cotton seeds were supplied by the Eastern Mediterranean Agricultural Research Institute. MC rates were applied manually using a calibrated twenty-liter sprayer on entire plots at two growth stages: at squaring (8 weeks after planting [WAP] in both years) and at the boll setting (11 WAP in both years).

Field Management Practices

To enhance soil tilth, disrupt capillary continuity, and suppress weed emergence, tractor hoeing was conducted four times before planting. Plant seeds were sown mechanically in the experimental plots, with each sub-subplot containing four rows, each 3 meters long, with a 70 cm spacing between rows and 20 cm spacing between plants within each row. Planting took place on May 26 in the first year and June 12 in the second year, at a depth of 5 cm below the soil surface. Irrigation was scheduled monthly for the first four months after sowing, resulting in a total of four irrigation events, and was terminated at the boll development stage. Fertilization involved the application of nitrogen (N) and phosphorus (P) fertilizers. Nitrogen was supplied at a total rate of 16 kg N ha^{-1} , with half applied as 20-20-0 compound fertilizer prior to sowing and the remaining half as ammonium nitrate (26% N) during the first irrigation. Phosphorus was applied entirely before sowing at a rate of 8 kg P ha^{-1} . Pest management included targeted chemical applications: Movento (150 mL ha^{-1}) for controlling aphids and leafhoppers, Mosplan 20 SP (60 g ha^{-1}) against whiteflies, and Neemarin (60 g ha^{-1}) to suppress green bollworm infestations. All other necessary agronomic

practices during the crop growth period were conducted as recommended.

Data collection

In the current finding, various parameters, including leaf area per plant, yield, seed index, individual fiber weight, moisture, fiber length, length uniformity, micronaire, spinning coefficient index, and short fiber index, were measured. Leaf area was measured using the Microscopy Image Analysis method (ImageJ software). Three plants were randomly selected from the two central rows, excluding 60 cm from both ends of each row. Leaf area per plant was obtained according to the method of Dharani et al., (2022), as indicated in equation (1). When the cotton bolls were fully mature and had opened, they were hand-harvested from ten plants in each plot to assess the seed cotton yield and 100-seed weight. The seed cotton was weighed using a scale with an accuracy of 0.01 g and then converted to kilograms per hectare ($\text{kg} \cdot \text{ha}^{-1}$) as indicated in equation (2). The harvested seed cotton was ginned to separate the fibers from the seeds, and then the 100-seed weight was measured using the aforementioned scale. For analyzing fiber characteristics, all fibers were sent to the fiber quality laboratory of the Eastern Mediterranean Agricultural Research Institute for assessment based on quality grade standards, using a fully automated High-Volume Instrument (HVI) device. Individual fiber weight was determined according to the method of Lee et al., (2023), with some modifications, using the equation (3).

$$\text{Leaf area per plant} = \text{averaged leaf area (cm}^2\text{)} * \text{number of leaves per plant} \dots (1)$$

$$\text{Seed cotton yield (kg. ha}^{-1}\text{)} = \text{amount weighed (kg)} \times 10,000 / \text{number of harvested plants} \times \text{harvested area in square meters} \dots (2)$$

$$\text{Individual fiber weight (}\mu\text{g)} = [\text{fiber length (cm)} \times \text{length uniformity (\%)} \times (\text{micronaire} * 10,000,000)] \dots (3)$$

Data analysis

The analysis of variance was performed using GenStat Discovery software (version 15.1), and mean comparisons were conducted using Duncan's Multiple Range Test ($p < 0.05$). All graphs were created using Excel software on Windows 21.

Results

Table 1 Physicochemical characteristics of the experimental soil profile (0–30 cm depth)

Clay (%)	Silt (%)	Sand (%)	Texture	PH	CaCO ₃ (%)	EC (ds/m)	P ₂ O ₅ (kg/ha)	K ₂ O (kg/ha)	Organic Matter (%)
33.7	43.7	22.6	CL	7.89	21.5	1.0	43.3	474.5	0.98

CL Clay Loam, *EC* Electrical Conductivity, *ds/m* deciSiemens per metre

Weather Characteristics

The monthly rainfall during the 2022–2023 cotton growing seasons in the Mediterranean region of Türkiye is illustrated in Fig. 2. Across the two years, rainfall was well distributed in November but declined markedly in July and September of 2023. The total precipitation during the seven-month growing period was comparable between years, with 172.80 mm in 2023 and 170.20 mm in 2022, aligning with long-term regional climatic data reported by Kızılsımsek et al., (2024) over the past 91 years. Climatic conditions in 2023 were slightly warmer and more humid than in 2022, with mean maximum and minimum temperatures of 32.32 °C and 17.40 °C, respectively, compared with 31.84 °C and 17.12 °C in 2022, and mean relative humidity values of 65.70 % and 64.39 % (Fig. 2) (TSMS, 2023, 2024).

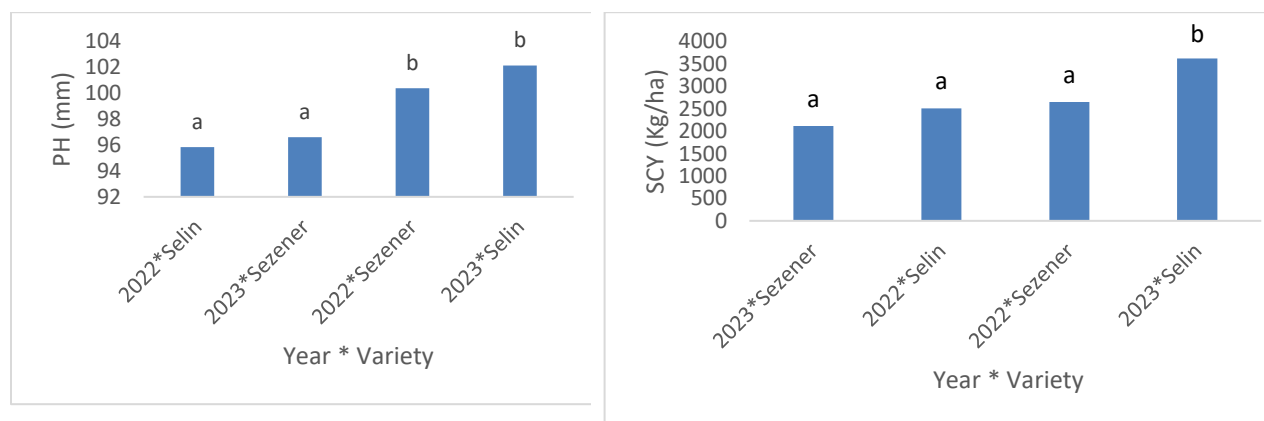


Fig. 1 Interaction of year and variety on PH and SCY. Different letters indicate significant difference at $p < 0.05$. *PH* Plant height, *SCY* Seed cotton yield

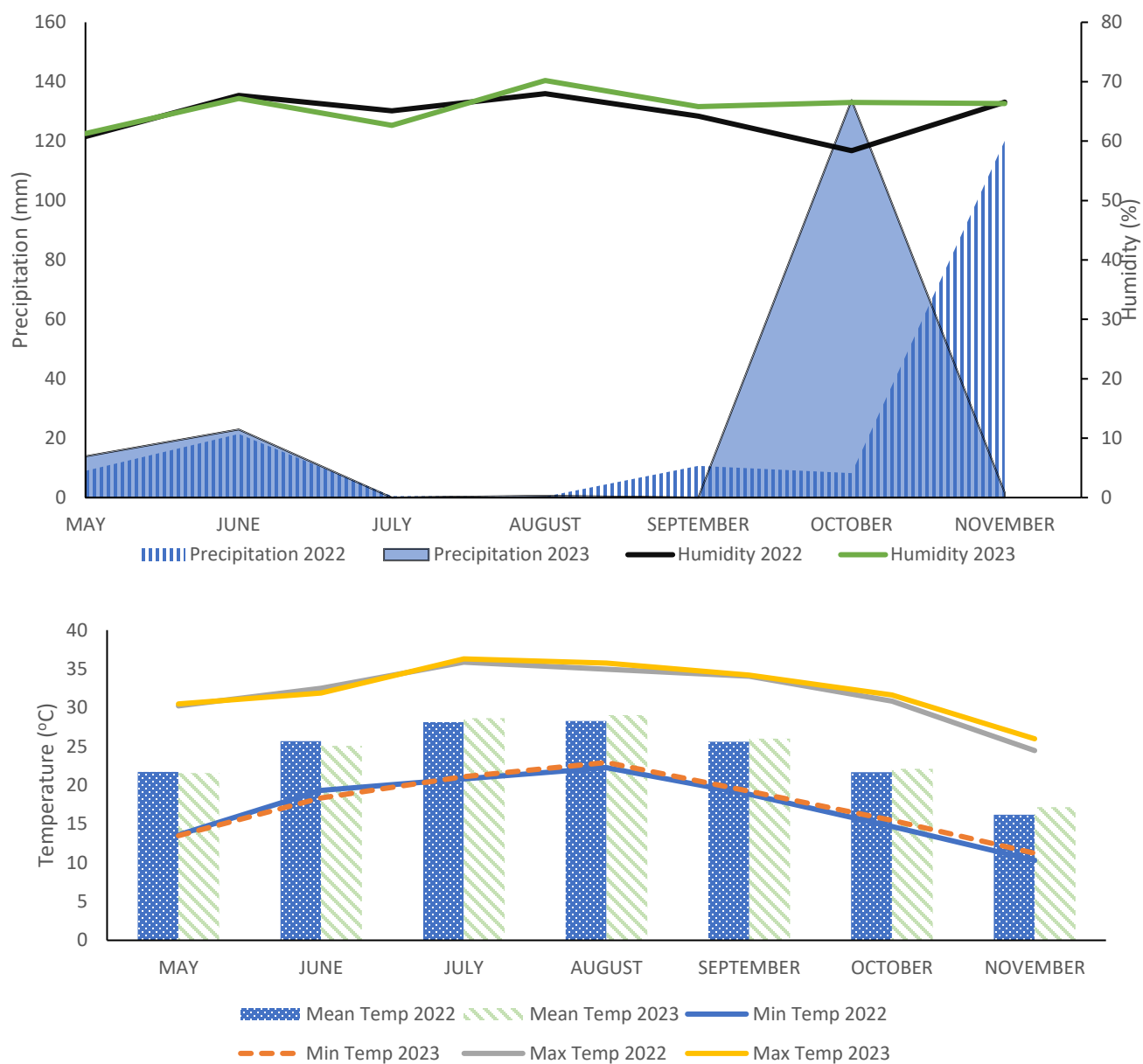


Fig. 2 Selected meteorological variables characterizing the experimental site during the 2022 - 2023 growing seasons

Table 2 Variance analysis of some morphological traits, yield, and yield components of different cotton varieties influenced by application timing and MC concentrations in Mediterranean region (2022–2023)

S.O.V	df	Means Square						
		PH	LA	NMB	BN	SCY	SI	IFW
Years (Y)	1	37.15 ^{ns}	1087610 [*]	78.24 ^{**}	13.02 ^{ns}	2001863 ^{ns}	0.24 ^{ns}	313.82 ^{**}
Rep (R)	2	44.98	48367	0.55	7.94	708263	0.3	3.55
Varieties (V)	1	5.77 ^{ns}	156763 ^{ns}	3.38 ^{ns}	30.56 [*]	11160378 ^{**}	85.15 ^{**}	5.14 [*]
Y × V	1	609.51 ^{**}	150 ^{ns}	0.09 ^{ns}	3.44 ^{ns}	16263421 ^{**}	0 ^{ns}	1.92 [*]
App. T (T)	1	398.01 ^{ns}	244861 ^{ns}	1.72 ^{ns}	16.95 ^{ns}	2254964 ^{ns}	0.49 ^{ns}	0 ^{ns}
Y × T	1	28.1 ^{ns}	61026 ^{ns}	4.24 ^{ns}	1.42 ^{ns}	843536 ^{ns}	0.06 ^{ns}	1.14 ^{ns}
V × T	1	94.05 ^{ns}	13852 ^{ns}	0.21 ^{ns}	0.39 ^{ns}	2575772 [*]	8.45 ^{**}	0.12 ^{ns}
CONCs (C)	3	98.13 ^{ns}	44603 ^{ns}	0.36 ^{ns}	10.84 ^{ns}	490371 ^{ns}	0.40 ^{ns}	0.39 ^{ns}
Y × C	3	104.02 ^{ns}	98731 ^{ns}	8.88 ^{ns}	10.22 ^{ns}	239307 ^{ns}	0.12 ^{ns}	0.32 ^{ns}
V × C	3	61.61 ^{ns}	49668 ^{ns}	2.75 ^{ns}	6.28 ^{ns}	464700 ^{ns}	0.13 ^{ns}	0.61 ^{ns}
T × C	3	270.07 ^{ns}	226266 ^{ns}	0.67 ^{ns}	7.07 ^{ns}	1382954 ^{ns}	0.07 ^{ns}	0.51 ^{ns}
Y × V × T	1	202.44 ^{ns}	625431 ^{ns}	0.21 ^{ns}	50.84 [*]	1860115 ^{ns}	0.03 ^{ns}	0.30 ^{ns}
Y × V × C	3	79.4 ^{ns}	94443 ^{ns}	1.43 ^{ns}	10.55 ^{ns}	682080 ^{ns}	0.19 ^{ns}	1.30 [*]
Y × T × C	3	204.31 ^{ns}	63592 ^{ns}	2.34 ^{ns}	4.58 ^{ns}	414517 ^{ns}	0.04 ^{ns}	1.11 ^{ns}
V × T × C	3	55.07 ^{ns}	37690 ^{ns}	3.25 ^{ns}	2.71 ^{ns}	1180945 ^{ns}	0.49 ^{ns}	0.20 ^{ns}
Y × V × T × C	3	27.68 ^{ns}	16288 ^{ns}	4.18 ^{ns}	18.06 ^{ns}	1220443 ^{ns}	0.08 ^{ns}	0.08 ^{ns}
Error		8.753	431.507	2.03	2.77	970.98	0.31	0.65
CV (%)		8.9	25.8	23.4	32	35.6	3.1	6.7

ns, * and ** no significant, significant in 5 and 1% level. *CONCs* Concentrations, *APP. T* Application timing, *PH* Plant height, *LA* Leaf Area, *NMB* Number of Monopodial Branches, *BN* Boll Number, *SCY* Seed Cotton Yield, *SI* Seed Index, *IFW* Individual Fiber Weight, *CV* Coefficient of variation, *S.O.V.* Sources of variations

Morphological Traits

Plant Height

Analysis of variance revealed a statistically significant interaction between year and variety on plant height ($p < 0.01$; Table 2). Post hoc comparisons indicated that the tallest plants were observed in the Selin variety in 2023 (102.14 cm) and the Sezener variety in 2022 (100.40 cm). In contrast, the shortest plants were recorded for the Sezener variety in 2023 (96.61 cm) and the Selin variety in 2022 (95.85 cm) (Fig. 1), underscoring the genotype-by-environment interaction effect on vegetative growth.

No significant main effects of year, concentration, variety, or application time were observed on plant height when considered independently (Table 2). However, a year-wise comparison exhibited that plant height was generally greater in 2023 compared to 2022 under MC treatments (Table 3). The maximum average plant height was recorded in 2023 (99.37 cm), corresponding to a 1.26% increase over the previous year.

Although not statistically significant, plant height was lowest under the 400 cc. ha⁻¹ MC application rate (96.80 cm), suggesting a potential inhibitory effect at this concentration. Similarly, plants treated with MCs at 8 WAP had the shortest mean height (96.71 cm), implying that later applications may suppress vertical growth (Table 3).

Leaf Area

The year significantly affected leaf area ($p \leq 0.05$; Table 2). Mean comparisons revealed that plants grown in 2022 exhibited larger leaf areas than those in 2023. The maximum average leaf area was 1775.90 cm² per plant in 2022, representing a 12.75% increase over 2023 (Table 3).

No statistically significant effects of PGR level, variety, application time, or their interactions were detected on leaf area (Table 2). Nevertheless, mean comparisons revealed some biologically meaningful patterns. Application of MC at 800 cc. ha⁻¹ produced the largest average leaf area (1721.33 cm² per plant), suggesting a potentially optimal concentration for leaf expansion. The Sezener variety responded with the highest increase in leaf area (4.84%) compared to Selin, though the difference was not significant (Table 3).

In terms of application timing, spraying at 8 WAP resulted in the lowest mean leaf area (1618.96 cm² per plant), whereas applications at 11 WAP yielded the highest (1719.97 cm² per plant), highlighting the possible importance of timing in maximizing foliar development.

Table 3 Effects of Mepiquat chloride concentrations and application timings on morphological traits, yield, and yield components of cotton varieties in the Mediterranean Region (2022–2023)

Treatments	Levels	PH	LA	NMB	BN	SCY	SI	IFW
Years	2022	98.13	1775.9 ^b	7.78 ^a	8.29	2581.75	10.02	7.98 ^a
	2023	99.37	1563.03 ^a	9.59 ^b	9.03	2870.56	9.92	11.59 ^b
	LSD0.05	3.64	179.42	0.85	1.15	403.72	0.13	0.27
Varieties	Selin	98.99	1629.05	8.87	9.22 ^b	3067.11 ^b	9.03 ^a	9.55 ^a
	Sezener	98.5	1709.87	8.5	8.1 ^a	2385.19 ^a	10.91 ^b	10.02 ^b
	LSD0.05	2.24	810.45	0.47	1.17	318.75	0.31	0.47
App. T	8 WAP	96.71	1618.96	8.82	8.24	2879.41	10.04	9.78
	11 WAP	100.78	1719.97	8.55	9.08	2572.89	9.9	9.79
	LSD0.05	4.88	380.49	1.14	1.12	342.82	0.16	0.26
CONCs	Control	97.26	1616.29	8.66	8.42	2740.46	9.79	9.65
	400	96.8	1664.83	8.65	7.83	2519.68	10.06	9.94
	400 + 400	100.04	1675.41	8.57	9.06	2822.33	10.06	9.82
	800	100.89	1721.33	8.86	9.33	2822.13	9.99	9.73
	LSD0.05	6.08	178.2	1.13	1.74	558.9	0.33	0.38

Different superscript letters (a, b) in each column indicate significant difference at $p < 0.05$. *CONCs* Concentrations, *APPT* Application timing, *PH* Plant height, *LA* Leaf Area, *NMB* Number of Monopodial Branches, *BN* Boll Number, *SCY* Seed Cotton Yield, *SI* Seed Index, *IFW* Individual Fiber Weight

Number of Monopodial Branches

A highly significant year effect was observed for the number of monopodial branches ($p \leq 0.01$; Table 2). Plants grown in 2023 developed more monopodial branches (9.59 per plant) compared to those grown in 2022 (7.78 per plant), indicating that seasonal variation may influence branch initiation and development (Table 3).

Although no significant differences were detected for MC level, variety, or application time (Table 2), mean comparisons recorded notable trends. The 800 cc. ha⁻¹ MC treatment resulted in the highest average number of monopodial branches (8.86 per plant). Among the varieties, Selin produced a slightly greater number of monopodial branches (8.87 per plant) compared to Sezener (8.50 per plant), although this difference was not statistically significant (Table 3).

Application timing also influenced branching: MC application at 8 WAP led to a higher number of monopodial branches (8.82 per plant), whereas the lowest was recorded with application at 11 WAP (8.55 per plant), suggesting early application may be more favorable for branch proliferation.

Yield and yield components

The analysis of variance revealed that the effects of cultivars and year $\times$ application timing $\times$ cultivar were significant on boll number. The effects of cultivars, year $\times$ cultivar and cultivar $\times$ application timing were also significant on seed cotton yield. Seed index was affected by cultivars and year $\times$ application timing. Moreover, individual fiber weight was influenced by years, cultivars, year $\times$ cultivar and year $\times$ cultivar $\times$ PGRs, and seed index was affected by cultivars, and cultivar $\times$ application timing (Table 2).

Seed Cotton Yield

According to the results (Table 3), the mean comparison of the year $\times$ variety interaction revealed that the Selin variety in 2023 produced the highest seed cotton yield (3623 kg/ha), which was 2118 kg/ha greater than the yield of the Sezener variety in 2022 (Fig. 1). In contrast, the application timing $\times$ variety interaction indicated that the lowest yield (2375 kg/ha) was recorded for the Sezener variety when MC was applied at 8 WAP (Fig. 3a).

When analyzed independently, the Selin variety exhibited the highest mean seed cotton yield (3067.11 kg/ha), which was 25.01% higher than that of the Sezener variety (2385.19 kg/ha) (Table 3). Among the Mepiquat chloride (MC) levels, the split application of 400 + 400 cc. ha⁻¹ produced the highest yield (2822.33 kg/ha), marginally surpassing the 800 cc. ha⁻¹ application (2822.13 kg/ha) (Table 3). In contrast, the 400 cc. ha⁻¹ treatment reduced seed cotton yield by 8.10% compared to the control (Table 3).

Table. 4 Interaction of year, variety and application timing on boll number, spinning consistency index, fiber length and uniformity index

Treatments			BN	SCI	UHML	UI
2022	Selin	8 WAP	7.33 ^a	138.10 ^{ab}	29.70 ^c	83.33 ^a
		11 WAP	10.00 ^c	141.50 ^{ab}	29.75 ^c	83.55 ^{ab}
	Sezener	8 WAP	8.17 ^b	145.00 ^{ab}	30.33 ^d	83.85 ^{ab}
		11 WAP	7.6 ^{ab}	134.20 ^a	29.47 ^c	83.21 ^a
2023	Selin	8 WAP	10.15 ^c	141.20 ^{ab}	28.35 ^b	84.83 ^c
		11 WAP	9.42 ^c	136.70 ^{ab}	27.75 ^a	84.17 ^{bc}
	Sezener	8 WAP	7.3 ^a	144.10 ^{ab}	29.52 ^c	84.81 ^c
		11 WAP	9.24 ^c	147.00 ^b	29.92 ^{cd}	85.62 ^d

Different superscript letters (a, b, c, d) in each column indicate significant difference at $p < 0.05$. *WAP* Weeks After Planting, *BN* Boll Number, *SCI* Spinning Consistency Index, *UHML* Upper Half Mean Length, *UI* Uniformity Index

Boll Number per Plant

Mean comparisons for boll number revealed that the varieties were grouped into two statistically distinct categories (Table 2). The Selin variety produced the highest number of bolls per plant, while the Sezener variety had the lowest (Table 3). In the 2023 growing year, the Selin variety reached a maximum of 10.15 bolls/plant when MC was applied at 8 WAP (Table 4).

Among the MC levels, the 800 cc. ha⁻¹ foliar application resulted in the highest boll number (9.33 bolls/plant), although it was not significantly different from the 400 + 400 cc. ha⁻¹ split application, which produced 9.06 bolls/plant. Remarkably, the 400 cc. ha⁻¹ treatment reduced boll number by 6.81% relative to the control (Table 3).

Individual Fiber Weight

As revealed in Table 3, the Sezener variety recorded the highest individual fiber weight (10.02 µg) compared to the other variety. Notably, in 2023, this variety produced 41.68% higher than that of the Selin variety in 2022, which had the lowest value (7.89 µg) (Fig. 6c). Year-wise comparisons indicated a significant increase in individual fiber weight in 2023 (11.59 µg) compared to 2022 (7.98 µg) (Table 3). Furthermore, the Sezener variety in 2023 recorded the highest individual fiber weight (12.42 µg) when treated with 400 cc. ha⁻¹ of MC (Table 5). This value represented a 48.11% and 50.56% increase relative to the control × Selin (7.71 µg) and 800 cc. ha⁻¹ × Selin (7.47 µg) treatments in 2023, respectively (Table 5).

Table 5 Interaction of year, variety and concentration on individual fiber weight, fiber length and micronaire

Treatments			IFW	UHML	Mic
2022	Selin	Control	7.71 ^a	29.88 ^c	3.08 ^a
		400	8.05 ^a	30.19 ^c	3.19 ^a
		400+400	8.32 ^a	29.82 ^{de}	3.32 ^a
		800	7.47 ^a	29.02 ^{bcd}	3.12 ^a
	Sezener	Control	8.16 ^a	29.62 ^{cde}	3.31 ^a
		400	8.22 ^a	29.86 ^c	3.29 ^a
		400+400	7.85 ^a	30.41 ^c	3.09 ^a
		800	8.04 ^a	29.71 ^{cde}	3.24 ^a
2023	Selin	Control	11.45 ^{bc}	28.31 ^{ab}	4.77 ^c
		400	11.09 ^b	28.07 ^a	4.68 ^{bc}
		400+400	11.08 ^b	28.05 ^a	4.68 ^{bc}
		800	11.26 ^{bc}	27.78 ^a	4.80 ^c
	Sezener	Control	11.27 ^{bc}	29.96 ^c	4.45 ^b
		400	12.42 ^c	30.08 ^c	4.83 ^c
		400+400	12.04 ^{bc}	28.92 ^{bc}	4.89 ^c
		800	12.13 ^{bc}	29.92 ^c	4.74 ^b

Different superscript letters (a, b, c, d, e) in each column indicate significant difference at $p < 0.05$. *IFW* Individual Fiber Weight, *UHML* Upper Half Mean Length, *Mic* Micronaire

Seed Index

The variety $\times$ application timing interaction significantly influenced seed index, with the lowest value (8.66) observed for the Selin variety when MC was applied at 11 WAP (Fig. 3b). Across both cropping seasons, the Sezener variety exhibited a significantly higher mean seed index (10.91) compared to Selin variety (9.03) under MC application ($P < 0.05$; Table 3, Fig. 3b).

No significant main effects were found for year, concentration, or application timing individually on seed index (Table 2). However, when analyzed by year, higher seed index values were observed under MC treatments in 2022 compared to 2023, with the maximum value (10.02) representing a modest 1% increase over 2023 (Table 3). Regarding MC levels, the control (0 cc. ha⁻¹) resulted in the lowest seed index (9.79), while the highest values (10.06) were observed under both 400 cc. ha⁻¹ and 400 + 400 cc. ha⁻¹ application rates. In terms of application timing, 8 WAP yielded a slightly higher seed index (10.04) compared to 11 WAP (9.90) (Table 3).

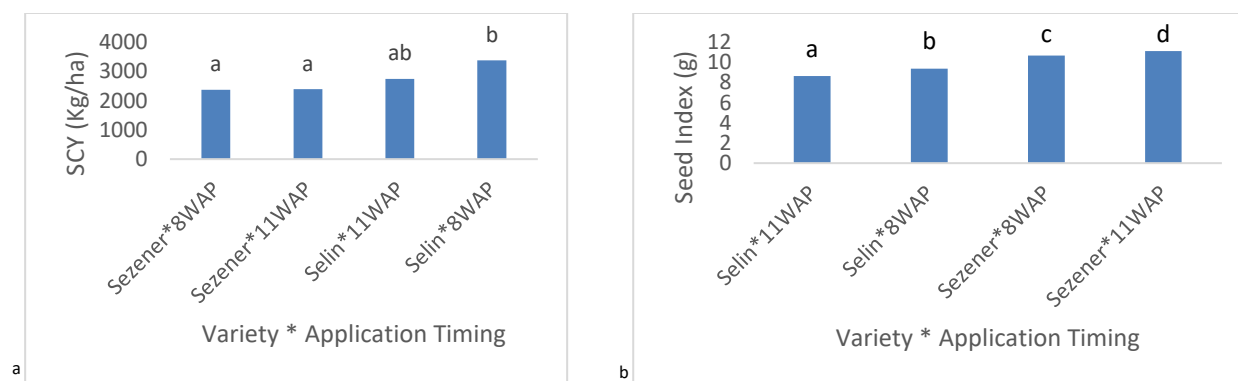


Figure 3 illustrates the interaction effects of variety and application timing on yield components, where (a) shows their interaction on seed cotton yield (SCY) and (b) on seed index (SI), with different letters indicating significant differences at $p < 0.05$.

Fiber Qualitative Properties

Table 6 Variance analysis of some fiber qualitative properties of different cotton varieties influenced by application timing and MC concentrations in Mediterranean region (2022–2023)

S.O.V	Means Square								
	df	Mst	SCI	SF	Elg	UHML	MIC	Str	UI
Years (Y)	1	6.96**	154.38 ^{ns}	35.79**	0.30*	20.60**	55.86**	384.99**	45.22**
Rep (R)	2	1.12	91.03	0.72	0.04	0.35	0.60	4.23	0.39
Varieties (V)	1	2.50*	247.77 ^{ns}	0.77 ^{ns}	0.35*	20.39**	0.01 ^{ns}	0.78 ^{ns}	3.92*
Y × V	1	1.79**	274.15 ^{ns}	0 ^{ns}	0.28 ^{ns}	13.41**	0.02 ^{ns}	3.73 ^{ns}	2.35*
App. T (T)	1	0.36**	119.02 ^{ns}	0.09 ^{ns}	0.00 ^{ns}	1.54 ^{ns}	0.02 ^{ns}	3.02 ^{ns}	0.11 ^{ns}
Y × T	1	0.31*	49.75 ^{ns}	0.04 ^{ns}	0.04 ^{ns}	0.56 ^{ns}	0.27*	1.00 ^{ns}	0.48 ^{ns}
V × T	1	0.02 ^{ns}	66.85 ^{ns}	1.10 ^{ns}	0.20 ^{ns}	0.01 ^{ns}	0.07 ^{ns}	12.43*	0.54 ^{ns}
CONCs (C)	3	0.05 ^{ns}	97.61 ^{ns}	0.36 ^{ns}	0.13 ^{ns}	0.88 ^{ns}	0.05 ^{ns}	1.48 ^{ns}	0.59 ^{ns}
Y × C	3	0.06 ^{ns}	200.92 ^{ns}	0.71 ^{ns}	0.05 ^{ns}	1.53*	0.04 ^{ns}	3.70 ^{ns}	1.40 ^{ns}
V × C	3	0.04 ^{ns}	136.66 ^{ns}	0.22 ^{ns}	0.08 ^{ns}	0.68 ^{ns}	0.03 ^{ns}	4.12 ^{ns}	2.10*
T × C	3	0.07 ^{ns}	103.04 ^{ns}	0.32 ^{ns}	0.03 ^{ns}	0.19 ^{ns}	0.03 ^{ns}	4.86 ^{ns}	1.90 ^{ns}
Y × V × T	1	0.02 ^{ns}	703.56**	1.59 ^{ns}	0.07 ^{ns}	5.53**	0.06 ^{ns}	2.24 ^{ns}	8.15**
Y × V × C	3	0.08 ^{ns}	64.03 ^{ns}	0.26 ^{ns}	0.01 ^{ns}	1.189*	0.26**	1.45 ^{ns}	0.64 ^{ns}
Y × T × C	3	0.02 ^{ns}	54.97 ^{ns}	0.29 ^{ns}	0.23*	0.49 ^{ns}	0.11 ^{ns}	2.93 ^{ns}	0.06 ^{ns}
V × T × C	3	0.01 ^{ns}	168.18 ^{ns}	0.96 ^{ns}	0.02 ^{ns}	0.81 ^{ns}	0.07 ^{ns}	1.04 ^{ns}	3.17**
Y × V × T × C	3	0.03 ^{ns}	9.63 ^{ns}	0.73 ^{ns}	0.06 ^{ns}	0.13 ^{ns}	0.01 ^{ns}	1.54 ^{ns}	0.83 ^{ns}
Error		0.23	9.31	0.67	0.28	0.65	0.25	1.75	0.86
CV (%)		2.6	6.6	8.1	5.0	2.20	6.30	5.70	1.00

ns, * and ** no significant, significant in 5 and 1% level. *CONCs* Concentrations, *T* Application timing, *MST* Moisture, *SCI* Spinning Consistency Index, *SF* Short Fibers, *Elg* Elongation, *UHML* Upper Half Mean Length, *MIC* Micronaire, *Str* Strength, *UI* Uniformity Index, *CV* Coefficient of variation, *S.O.V.* Sources of variations

Moisture Content

Analysis of variance showed that year had a significant effect on fiber moisture content ($p \leq 0.01$; Table 6). Mean comparisons indicated that the fiber moisture content in the second year was higher than in the first year. Specifically, the moisture content was 8.94% in 2023, representing a 6.23% increase compared with 2022 (Table 7).

Varieties also significantly influenced fiber moisture content ($p < 0.05$; Table 6). Across varieties, Selin exhibited higher moisture content (8.83%) than Sezener (8.51%) under MC treatment (Table 7). Furthermore, the year $\times$ variety interaction was significant ($p < 0.05$; Table 6); the highest moisture content (8.97%) was recorded for Selin in 2023, which was 10.03% greater than that of Sezener in 2022 (Fig. 4a).

Application timing significantly affected fiber moisture content ($p < 0.01$; Table 6). The lowest moisture content (8.61%) was observed when MC was applied at 11 WAP (Table 7). The year $\times$ application timing interaction was also significant ($p < 0.05$; Table 6). The 8 WAP treatment recorded the highest moisture content values (8.95% in 2023), whereas other timings showed relatively lower values (Fig. 4b).

In contrast, moisture content did not differ significantly ($p > 0.05$; Table 6) among MC application rates across both varieties. Nevertheless, the control (0 cc. ha⁻¹) treatment recorded the highest mean moisture content (8.73%) (Table 6).

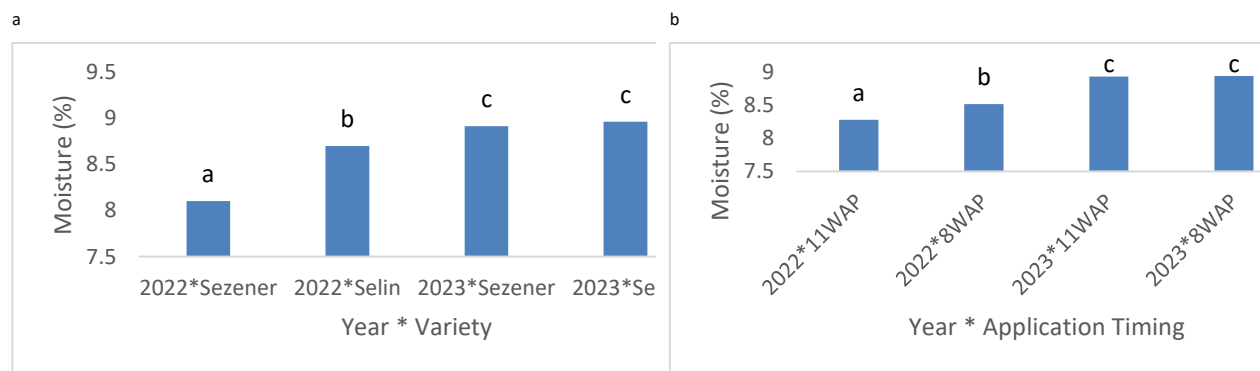


Figure 4 illustrates the interaction effects on moisture, where (a) shows the interaction between variety and year, and (b) depicts the interaction between variety and application timing, with different letters indicating significant differences at $p < 0.05$.

Spinning Consistency Index (SCI)

The analysis of variance revealed a significant ($p < 0.01$; Table 6) three-way interaction among year $\times$ application timing $\times$ variety for the Spinning Consistency Index (SCI). Under varying MC application rates, the Sezener variety exhibited a significantly higher SCI (147.00) in 2023 when MC was applied at 11 WAP, whereas the lowest SCI (134.20) for this variety was recorded in 2022 (Table 4). Conversely, in the Selin variety, the SCI was slightly higher in 2022 (141.50) when MC was applied at 11 WAP than in 2023 (141.20) when MC was applied at 8 WAP (Table 4).

No significant main effects of year, variety, MC concentration, or application timing were detected when considered individually (Table 6). However, when the data were analyzed separately by year, higher SCI values were observed under Mepiquat chloride (MC) treatments in 2023 compared to 2022, with the maximum mean SCI (142.24) representing a modest 1.79% increase relative to 2022 (Table 7). Across MC levels, the control treatment (0 cc. ha⁻¹) produced the highest SCI (142.27), whereas the lowest value (137.97) was recorded under the 800 cc. ha⁻¹ rate. Regarding application timing, 8 WAP resulted in a slightly higher SCI (142.09) than 11 WAP (139.86) (Table 7).

Short Fiber Content

Analysis of variance revealed that the year had a significant effect on short fiber content ($p \leq 0.01$; Table 6). Mean comparisons showed that short fiber content was higher in 2022 (8.85%) than in 2023, reflecting a 14.81% decrease in the second year (Table 7).

No significant main effects of variety, MC concentration, or application timing, nor their interactions, were perceived when analyzed collectively (Table 6). However, within varieties, MC application resulted in higher short fiber content in Selin (8.33%) than in Sezener (8.15%) (Table 7). Across MC application doses, the 800 cc ha⁻¹ treatment produced the highest short fiber content (8.40%), while the lowest value (8.10%) was recorded under the split 400 + 400 cc ha⁻¹ rate (Table 7). MC applied at 11 WAP resulted in slightly higher short fiber content (8.27%) than at 8 WAP (8.21%) (Table 7).

Table 7 Effects of Mepiquat chloride concentrations and application timings on fiber qualitative properties of cotton varieties in the Mediterranean Region (2022–2023)

Treatments	Levels	Mst	SCI	SF	Elg	UHML	Mic	Str	UI
Years	2022	8.4 ^a	139.71	8.85 ^b	5.44 ^a	29.81 ^b	3.21 ^a	28.68 ^a	83.48 ^a
	2023	8.94 ^b	142.24	7.63 ^a	5.55 ^b	28.89 ^a	4.73 ^b	32.69 ^b	84.86 ^b
	LSD0.05	0.1	3.87	0.28	0.11	0.27	0.10	0.71	0.35
Varieties	Selin	8.83 ^b	139.37	8.33	5.56 ^b	28.89 ^a	3.96	30.78	83.97 ^a
	Sezener	8.51 ^a	142.58	8.15	5.44 ^a	29.81 ^b	3.98	30.60	84.37 ^b
	LSD0.05	0.17	6.44	0.4	0.11	0.27	0.10	0.71	0.35
App. T	8 WAP	8.73 ^b	142.09	8.21	5.50	29.48	3.95	30.86	84.20
	11 WAP	8.61 ^a	139.86	8.27	5.49	29.22	3.98	30.51	84.14
	LSD0.05	0.07	3.83	0.4	0.11	0.27	0.10	0.71	0.35
CONCs	Control	8.73	142.27	8.22	5.56	29.44	3.90	30.98	84.10
	400	8.69	141.94	8.24	5.52	29.55	4.00	30.57	84.32
	400 + 400	8.64	141.73	8.1	5.51	29.30	4.00	30.79	84.28
	800	8.63	137.97	8.4	5.39	29.11	3.97	30.41	83.98
	LSD0.05	0.11	5.41	0.37	0.16	0.38	0.14	1.01	0.50

Different superscript letters (a, b) in each column indicate significant difference at $p < 0.05$. *CONCs* Concentrations, *APPT* Application timing, *MST* Moisture, *SCI* Spinning Consistency Index, *SF* Short Fibers, *Elg* Elongation, *UHML* Upper Half Mean Length, *MIC* Micronaire, *Str* Strength, *UI* Uniformity Index

Fiber Elongation

Analysis of variance indicated that the year had a significant effect on fiber elongation ($p < 0.05$; Table 6). Mean comparison revealed that fiber elongation was higher in 2023 (5.55%) than in 2022, corresponding to a 2% reduction in the first year (Table 7). Varietal differences were also significant ($p < 0.05$; Table 6), with Selin exhibiting greater fiber elongation (5.56%) than Sezener (5.44%) under MC treatment (Table 7). Moreover, a significant three-way interaction among year, application timing, and concentration was detected ($p < 0.05$; Table 6). The highest fiber elongation (5.80%) occurred in the control treatment in 2023 when MC was applied at 8 WAP, whereas the lowest value (5.27%) was recorded in 2022 under the 800 cc. ha⁻¹ treatment at the same timing (Table 8).

Table. 8 Interaction of year, application timing and concentration on fiber elongation

		Fiber Elongation			
	Treatments	Control	400	400+400	800
2022	8 WAP	5.37 ^a	5.50 ^{ab}	5.55 ^{ab}	5.27 ^a
	11 WAP	5.62 ^{ab}	5.55 ^{ab}	5.35 ^a	5.32 ^a
2023	8 WAP	5.80 ^b	5.58 ^{ab}	5.51 ^{ab}	5.42 ^{ab}
	11 WAP	5.46 ^{ab}	5.44 ^{ab}	5.64 ^{ab}	5.56 ^{ab}

Different superscript letters (a, b,) in each column indicate significant difference at $p < 0.05$. *WAP* Weeks After Planting

Fiber Length

Analysis of variance exhibited a significant effect of year on fiber length ($p < 0.01$; Table 6). Mean comparison indicated that the longest fibers (29.81 mm) were recorded in 2022, representing a 3.13% reduction in 2023 (Table 7). Varietal differences were significant ($p < 0.01$; Table 6), with Sezener producing longer fibers (29.81 mm) than Selin (28.89 mm) under MC treatment (Table 7). A significant year $\times$ variety interaction was detected ($p < 0.01$; Table 6); Sezener in 2022 unveiled the longest fibers (29.90 mm), which were 6.30% longer than those of Selin in 2023 (Fig. 5a).

A significant year $\times$ concentration interaction was also observed ($p < 0.05$; Table 6). The longest fibers (30.12 mm) occurred under the 400+400 cc. ha⁻¹ treatment in 2022, while the shortest fibers (28.49 mm) were recorded under the same treatment in 2023 (Fig. 6a). Furthermore, a significant three-way interaction (year $\times$ application timing $\times$ variety) was identified ($p < 0.01$; Table 6). Sezener produced the longest fibers (30.33 mm) in 2022 when MC was applied at 8 WAP, whereas the shortest fibers (27.75 mm) were recorded for Selin in 2022 at 11 WAP (Table 4). Additionally, the year $\times$ variety $\times$ concentration interaction was significant ($p < 0.05$; Table 6), with Sezener treated with 400 + 400 cc. ha⁻¹ MC in 2022 exhibiting the longest fibers (30.41 mm), representing an 8.69% increase compared with the 800 cc. ha⁻¹ $\times$ Selin treatment (27.78 mm) in 2023 (Table 5).

Fiber Micronaire

Analysis of variance showed that the year had a significant effect on fiber micronaire ($p < 0.01$; Table 6). In 2023, varieties supplied with Mepiquat chloride exhibited significantly higher micronaire values (4.73 $\mu\text{g inch}^{-1}$) than in 2022 (3.21 $\mu\text{g inch}^{-1}$) (Table 7). A significant year $\times$

application timing interaction was also observed ($p < 0.05$; Table 6). The highest micronaire ($4.77 \mu\text{g inch}^{-1}$) was recorded under the 8 WAP treatment in 2023, whereas other timings resulted in comparatively lower values (Fig. 5b).

Moreover, a significant three-way interaction among year, variety, and concentration was detected ($p < 0.01$; Table 6). The Sezener variety in 2023 revealed the highest micronaire ($4.89 \mu\text{g inch}^{-1}$) when treated with $400 + 400 \text{ cc. ha}^{-1}$ of MC (Table 5), representing a 45.59% increase compared with the control $\times$ Selin treatment ($3.08 \mu\text{g inch}^{-1}$) in 2022.



Figure 5 illustrates the interaction effects on fiber quality traits, where (a) shows the interaction between variety and year on fiber length, (b) presents the interaction between year and application timing on micronaire, (c) depicts the interaction between variety and year on fiber uniformity, and (d) shows the interaction between variety and application timing on fiber strength, with different letters indicating significant differences at $p < 0.05$.

Fiber Strength

Analysis of variance indicated that the year had a significant effect on fiber strength ($p < 0.01$; Table 6). Mean comparison exhibited that fiber strength was higher in 2023 (32.69 g tex^{-1}) than in 2022 (28.68 g tex^{-1}), representing a 13.07% increase in the second year (Table 7). A significant two-way interaction between variety and application timing was also perceived ($p <$

0.05; Table 6). The Sezener variety exhibited the highest fiber strength (31.13 g tex^{-1}) when MC was applied 8 WAP, while the lowest strength (30.06 g tex^{-1}) was observed for the same variety when MC was applied at 11 WAP (Fig. 5d).

Although differences among MC concentrations were not statistically significant ($p > 0.05$; Table 6), mean comparisons unveiled notable trends. The control treatment (0 cc. ha^{-1}) resulted in the highest fiber strength (30.98 g tex^{-1}), followed by $400 + 400 \text{ cc. ha}^{-1}$ (30.79 g tex^{-1}), 400 cc. ha^{-1} (30.57 g tex^{-1}), and 800 cc. ha^{-1} (30.41 g tex^{-1}) (Table 7).

Fiber Uniformity

Analysis of variance revealed that the year had a significant effect on fiber uniformity ($p < 0.01$; Table 6). Mean comparison exhibited that fiber uniformity was higher in 2023 (84.86%) than in 2022 (83.48%), representing a 1.64% increase in the second year (Table 7). Varietal differences were also significant ($p < 0.05$; Table 6), with Sezener recording higher fiber uniformity (84.37%) than Selin (83.97%) under MC treatment (Table 7).

A significant year $\times$ variety interaction was observed ($p < 0.05$; Table 6); Sezener in 2023 recorded the highest fiber uniformity (85.21%), 2.10% higher than Selin in 2022 (Fig. 5c). The variety $\times$ concentration interaction was also significant ($p < 0.05$; Table 7), with Sezener treated with 400 cc/da showing the highest fiber uniformity (84.64%), while Selin treated with 800 cc/da exhibiting the lowest (83.44%) (Fig. 6b).

Furthermore, a significant three-way interaction among year, application timing, and variety was detected ($p < 0.01$; Table 6). Under varying MC application rates, Sezener attained the highest fiber uniformity (85.62%) in 2023 when MC was applied at 11 WAP, while the lowest uniformity (83.21%) was recorded for the same variety in 2022 at the same timing (Table 4). Additionally, the variety $\times$ application timing $\times$ concentration interaction was significant ($p < 0.01$; Table 6). The Sezener treated with 400 cc. ha^{-1} at 11 WAP unveiled the highest fiber uniformity (85.09%), representing a 2.58% increase compared with the Selin $\times$ 800 cc. ha^{-1} treatment (82.92%) at the 8 WAP (Table 9).

Table. 9 Interaction of variety, application timing and concentration on uniformity index.

		Uniformity index			
Treatments		Control	400	400+400	800
Selin	8 WAP	84.93 ^{de}	83.86 ^{abcd}	84.59 ^{bcd}	82.92 ^a
	11 WAP	83.58 ^{ab}	84.14 ^{bcd}	83.76 ^{abcd}	83.96 ^{abcde}
Sezener	8 WAP	83.72 ^{abc}	84.18 ^{bcd}	84.58 ^{bcd}	84.84 ^{cde}
	11 WAP	84.18 ^{bcd}	85.09 ^c	84.18 ^{bcd}	84.20 ^{bcd}

Different superscript letters (a, b, c, d, e) in each column indicate significant difference at $p < 0.05$. *WAP* Weeks After Planting

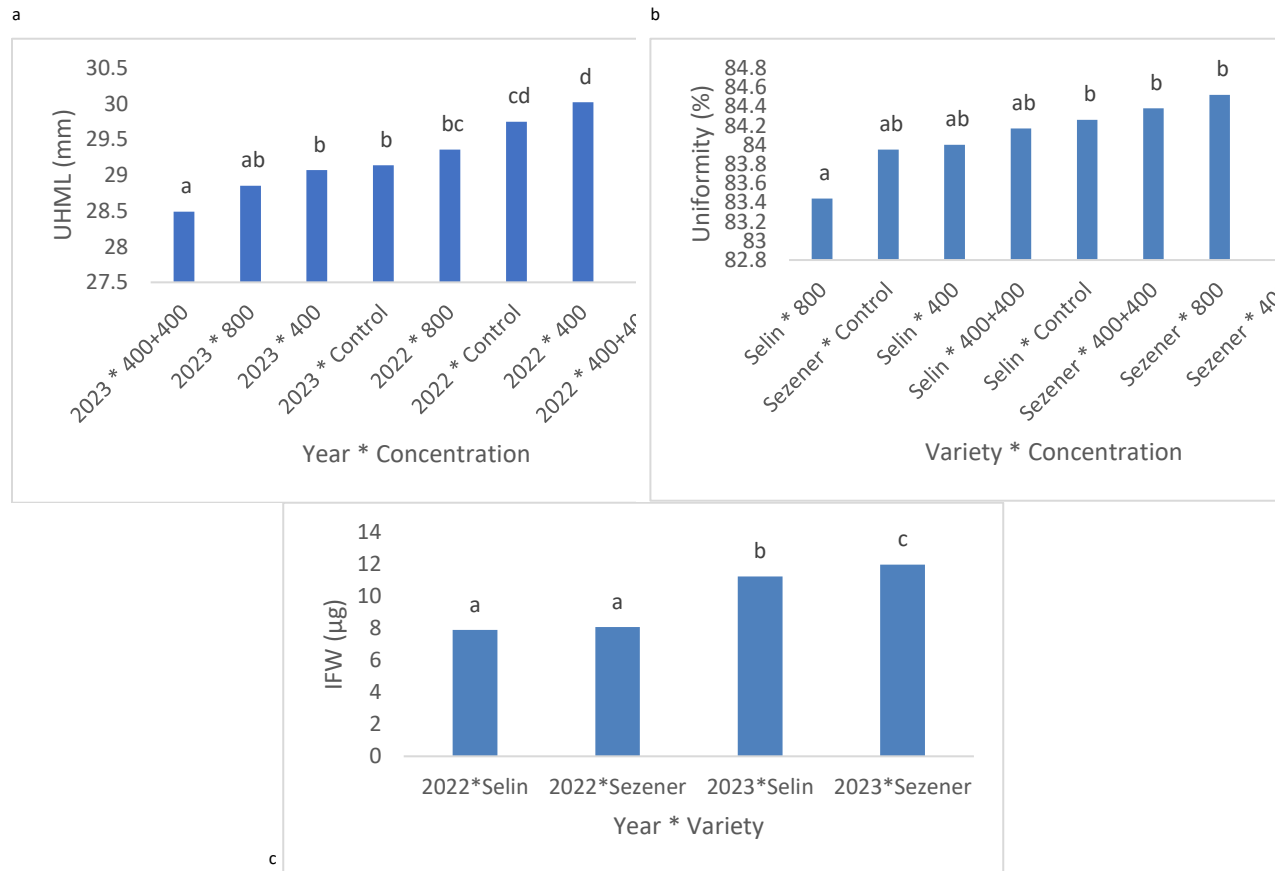


Figure 6 illustrates the interaction effects on fiber parameters, where (a) shows the interaction between year and concentration on fiber length (UHML), (b) presents the interaction between variety and concentration on uniformity index (UI), and (c) depicts the interaction between year and variety on individual fiber weight (IFW), with different letters indicating significant differences at $p < 0.05$.

Discussion

Morphological Adjustments and Yield Components

The present study demonstrates that genotype, environment, and MC application interactively regulate cotton growth dynamics, yield formation, and fiber quality attributes. The significant year $\times$ variety interaction for plant height and leaf area underscores the strong genotype $\times$ environment ($G \times E$) influence on vegetative development, consistent with earlier studies showing that climatic variability and cultivar-specific growth habits shape cotton responses to growth regulators (Hu et al., 2023; Tung et al., 2018). The reduction in plant height and leaf expansion with 400 cc ha⁻¹ MC concentration or earlier application aligns with its known anti-gibberellin mode of action, which restricts vegetative vigor and redirects assimilates toward reproductive sinks (Dharani et al., 2022; Lee et al., 2023; Priyadarshini et al., 2023; Priyanka et al., 2022).

Environmental conditions exerted a significant influence on monopodial branching, with water deficit conditions reducing branch formation and subsequently influencing fiber yield and quality. This aligns with previous observations that abiotic stress limits vegetative branching and reproductive potential (Ayele et al., 2020; Tlatlaa et al., 2023a). Although varietal differences in branch number were not significant across years, the results emphasize that branch development depends on a complex interplay of genotype, environment, growth stage, and growth regulator application. Optimizing these factors is crucial, as monopodial branches contribute substantially to reproductive capacity and yield performance (Abbas et al., 2022; Altun & Karademir, 2024; Murtza et al., 2022).

Early MC application enhanced monopodial branching and boll formation, demonstrating that precise timing is critical for maximizing sink strength at the onset of reproductive development (Singh et al., 2017). This physiological advantage was particularly evident in the Selin cultivar, which exhibited a superior source–sink balance and reproductive efficiency compared to Sezener. These findings corroborate previous reports highlighting cultivar-specific yield responses to MC and the necessity of genotype-targeted growth regulator strategies (Dharani et al., 2022; Malima et al., 2025a; Zhao et al., 2017).

MC application variably influenced yield components such as seed index, seed cotton yield, and individual fiber weight. Enhanced yield, seed index and fiber weight in MC-treated plants likely resulted from improved physiological and biochemical activity, including increased carotenoid and chlorophyll content, higher stomatal conductance, and enhanced enzyme activities, all of which support efficient carbon assimilation, carbohydrate metabolism, and protein and sugar biosynthesis (Luo et al., 2023; Wu et al., 2025). Moreover, morphological adjustments—such as reduced canopy size, improved light penetration, increased monopodial branches, and a lower height-to-node ratio— further enhanced photoassimilate partitioning to reproductive structures, improving boll development and yield potential (Abbas et al., 2022; Ahmad et al., 2025; Meng et al., 2023).

Fiber Quality Responses to MC Management

Moisture content, which strongly affects fiber quality traits, was affected by variety, seasonal conditions, and MC application timing. A notable reduction in moisture content with split or moderate MC doses applied at later stages advocates that delayed application may enhance secondary wall deposition and promote fiber maturation, consistent with (Al-Khayri et al., 2024). In contrast, the higher moisture content in untreated plants indicates a potential trade-off between growth regulation and fiber quality (Abia et al., 2025). The consistently lower moisture levels observed in the Sezener variety underscore inherent genotypic differences in fiber physiology, reflecting the role of intrinsic metabolic traits in fiber development (Beegum et al., 2025; Jia et al., 2024). Moreover, the profound impact of climatic variability on short fiber content and moisture levels reinforces the complexity of genotype–environment interactions that collectively determine cotton fiber development and quality attributes (Darawsheh et al., 2022; Tlatlaa et al., 2024). The detected reduction in short fiber content under optimized MC regimes further confirms that growth regulator management can modulate fiber structural properties beyond yield-related components (Chalise et al., 2022; Leal et al., 2020).

Fiber elongation, crucial for yarn strength and spinning performance, was significantly higher in 2023 and in the Selin variety under MC treatment. Year-to-year variation is likely due to climatic influences on fiber cell wall elongation and secondary wall formation (Thapliyal et al., 2023; Zhao et al., 2019). The significant year $\times$ application timing $\times$ concentration interaction indicates that MC can modulate fiber elongation dynamics, likely by influencing assimilate partitioning

during fiber development (Wu et al., 2025). Notably, the highest elongation was recorded in the untreated conditions, suggesting that suboptimal or excessive MC suppression can hinder fiber extensibility. Fiber length, vital for spinning efficiency, was consistently greater in Sezener, with significant effects of year and treatment interactions. Enhanced fiber length with split or moderate MC application suggests that balanced vegetative control supports optimal fiber elongation, whereas excessive doses or delayed applications may inhibit cell elongation (Wu et al., 2025).

Micronaire, a key determinant of fiber fineness and maturity, was higher in 2023, particularly in Sezener treated with moderate MC doses, reflecting thicker and more mature fibers (Zhang et al., 2020). Environmental conditions, especially temperature during boll maturation, likely contributed to these differences (Raphael et al., 2024). The significant three-way interaction among year, variety, and concentration demonstrates genotype-specific sensitivity to MC, where moderate doses promote secondary wall thickening, while excessive levels can dilute assimilate availability and reduce fiber maturity (Malima et al., 2025b).

Fiber strength, determined by cell wall thickness, fiber length, and cellulose content, was significantly higher in 2023 and influenced by the variety $\times$ application timing interaction. Sezener achieved the highest strength when MC was applied at 8 WAP, suggesting that early growth regulation enhances cellulose deposition and fiber structural integrity. However, these results contrast with the findings reported by (Murtza et al., 2022). Although MC concentration effects were not statistically significant, trends indicated that low or split applications promote fiber reinforcement without compromising plant vigor. Finally, fiber uniformity, which affects yarn evenness and quality, was highest in 2023 for Sezener, with significant interactions involving all studied factors (Table 9). Improved uniformity with moderate MC application (400 cc. ha⁻¹ at 11 WAP) suggests that balanced growth control and synchronized boll development reduce variability in fiber maturity (Murtza et al., 2022). Excessive or poorly timed MC applications, however, may disrupt developmental synchrony, resulting in uneven fiber formation. These findings reinforce the importance of aligning MC management with varietal characteristics and environmental conditions to optimize fiber uniformity and quality (Chen et al., 2021).

Conclusions

This study demonstrates that genotype, environmental conditions, and Mepiquat chloride (MC) management interact significantly to influence cotton growth dynamics, yield formation, and fiber quality. The results highlight that optimizing MC application particularly through split or moderate-dose treatments (e.g., 400 + 400 cc. ha⁻¹) can effectively regulate vegetative growth, enhance yield components, and improve key fiber traits such as micronaire, strength, and uniformity. Early-to-mid reproductive stage applications (around 8 weeks after planting) are more effective in enhancing branching and boll development, whereas slightly later applications can improve fiber uniformity and micronaire. Genotypic differences were evident: Selin unveiling superior yield potential, while Sezener exhibited advantages in fiber quality attributes, signifying that cultivar selection should align with production goals to enable targeted management strategies. Seasonal variability further emphasized the importance of aligning MC strategies with environmental conditions to maximize agronomic performance; therefore, application strategies should be tailored to prevailing climatic conditions and soil fertility status. Collectively, these findings provide a scientific basis for integrating growth regulator management with genotype selection to achieve balanced growth, improved yield, and superior fiber quality under Mediterranean production systems. Hence, further studies should focus on integrating physiological, molecular, and agronomic approaches to refine MC use efficiency across diverse genotypes and environments, ultimately facilitating the development of decision-support tools to promote sustainable cotton production and meet fiber industry requirements.

Declarations

Ethics approval and consent to participate: Not applicable.

Consent for publication: Not applicable.

Data availability and materials: The data that support the findings of this study are accessible from the corresponding author upon reasonable request. There are no restrictions on data availability once the request has been approved.

Competing interests: The authors declare that they have no competing interests.

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Authors' contributions: **Malima M:** Conceptualization, experiments, methodology, writing original draft, writing-reviewing and editing preparation; **Kazungu S:** Software, formal analysis; **Kurt O:** Supervision, conceptualization, review, and editing; **Deus T:** Review, and editing; **Hacikamiloğlu MS:** methodology, software, data acquisition. All authors read and approved the final manuscript.

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References

- Abbas H, Wahid MA, Sattar A, Tung SA, Saleem MF, Irshad S, Alkahtani J, Elshikh MS, Cheema M, Li, Y. Foliar application of mepiquat chloride and nitrogen improves yield and fiber quality traits of cotton (*Gossypium hirsutum* L.). *PLoS ONE*. 2022;17(6 June). <https://doi.org/10.1371/journal.pone.0268907>
- Abia Y, Iram S, Ghulam S, Amna N, Jamshaid ALIJ, Muhammad F, Jehanzeb F. impact of plant growth regulators on yield and fiber quality in cotton (*Gossypium hirsutum*). *Integrative plant biotechnology Учёбуемелу: Roots Press*. 2025;3(1), 29–37.
- Ahmad I, Guanglong Z, Zhou G, Younas MU, Yan X. Melatonin and mepiquat chloride impact on cotton growth, physiological and yield at different growth stages. *Industrial Crops and Products*. 2025;226, 120702.
- Al-Khayri JM, Arif M, Kareem SHS, Anwar A, Dehghanisanij H, Emami S, Yasmeen A, Aftab K, Negm M. Exogenous application of bio-stimulants and growth retardants improve nutrient absorption and fiber quality in upland cotton. *Journal of Cotton Research*. 2024;7(1), 15.
- Altun D, Karademir E. Determination of Yield and Yield Criteria of Different Cotton Lines and Varieties. *Adnan Menderes Üniversitesi Ziraat Fakültesi Dergisi*. 2024;21, 37–44.
- Amissah S, Baidoo M, Agyei BK, Ankomah G, Black RA, Perry CD, Hollifield S, Kusi NY, Harris GH, Sintim HY. Early and Late Season Nutrient Stress Conditions: Impact on Cotton Productivity and Quality. *Agronomy*. 2023;13(1). <https://doi.org/10.3390/agronomy13010064>

- Arekhi, E, Ghasemi BK, Ajam NH, Faghani E. The Effect of Growth Regulators on Biochemical Properties, Yield, and Fiber Quality of Different Cultivars of cotton (*Gossypium Hirsutum*) Under Different Irrigation Intervals. *Journal of Plant Growth Regulation*. 2023;42(9), 5574–5586. <https://doi.org/10.1007/s00344-023-10937-w>
- Ayele AG, Dever JK, Kelly CM, Sheehan M, Morgan V, Payton P. Responses of upland cotton (*Gossypium hirsutum* L.) lines to irrigated and rainfed conditions of texas high plains. *Plants*. 2020;9(11). <https://doi.org/10.3390/plants9111598>
- Beegum S, Hassan MA, Reddy KN, Reddy V, Reddy KR. Assessing fiber quality variability among modern upland cotton cultivars and incorporating it into the GOSSYM-based fiber quality simulation model. *Journal of Cotton Research*. 2025; 8(1), 18.
- Beegum S, Reddy V, Reddy KR. Development of a cotton fiber quality simulation module and its incorporation into cotton crop growth and development model: GOSSYM. *Computers and Electronics in Agriculture*. 2023;212. <https://doi.org/10.1016/j.compag.2023.108080>
- Çelik S. Assessing Drought Tolerance in a Large Number of Upland Cotton Plants (*Gossypium hirsutum* L.) under Different Irrigation Regimes at the Seedling Stage. *Life*. 2023;13(10). <https://doi.org/10.3390/life13102067>
- Chalise DP, Snider JL, Hand LC, Roberts P, Vellidis G, Ermanis A, Collins GD, Lacerda LN, Cohen Y, Pokhrel A, Parkash V, Lee JM. Cultivar, irrigation management, and mepiquat chloride strategy: Effects on cotton growth, maturity, yield, and fiber quality. *Field Crops Research*. 2022;286. <https://doi.org/10.1016/j.fcr.2022.108633>
- Chen Y, Liu Z, yu, Heng L, Leila IMT, Zhang X, Chen D, hua. Effects of plant density and mepiquat chloride application on cotton boll setting in wheat–cotton double cropping system. *Journal of Integrative Agriculture*. 2021;20(9),2372–2381. [https://doi.org/10.1016/S2095-3119\(20\)63286-5](https://doi.org/10.1016/S2095-3119(20)63286-5)
- Cinar V, Balcı Ş, Ünay A. Yield and Fiber Quality Traits of Mutation-Based IMI Tolerant Cotton (*Gossypium hirsutum* L.) Lines. *Adnan Menderes Üniversitesi Ziraat Fakültesi Dergisi*. 2024;21, 9–17. <https://doi.org/10.25308/aduziraat.1265542>
- Çınar VM, Balcı Ş, Şimşek MK, Ünay A. Breeding of brown cotton for spinnable yarn in intraspecific and interspecific hybrids (*G. hirsutum* L. and *G. barbadense* L.). *Industrial Crops and Products*, 2023;202. <https://doi.org/10.1016/j.indcrop.2023.116995>
- Damalas CA, Koutroubas SD. Current status of herbicide resistance in global cotton production: trends and perspectives. *Crop Protection*, 2025;107320.
- Darawsheh MK, Beslemes D, Kouneli V, Tigka E, Bilalis D, Roussis I, Karydogianni S, Mavroeidis A, Triantafyllidis V, Kosma C, Zotos A, Kakabouki I. Environmental and Regional Effects on Fiber Quality of Cotton Cultivated in Greece. *Agronomy*. 2022;12(4). <https://doi.org/10.3390/agronomy12040943>
- Dharani K, Ravichandran V, Anandakumar S, Sritharan N, Sakthivel N. Impact of Growth Retardant and Defoliant on Morpho-physiological Traits and Yield Improvement in Cotton. *International Journal of Plant & Soil Science*. 2022;34(20),635–644. <https://doi.org/10.9734/ijpss/2022/v34i2031198>

- EL Sabagh A, Islam MS, Hossain A, Iqbal MA, Mubeen M, Waleed M, Reginato M, Battaglia M, Ahmed S, Rehman A, Arif M, Athar HUR, Ratnasekera D, Danish S, Raza MA, Rajendran K, Mushtaq M, Skalicky M, Brestic M, Abdelhamid MT. Phytohormones as Growth Regulators During Abiotic Stress Tolerance in Plants. *Frontiers in Agronomy*. 2022;4. <https://doi.org/10.3389/fagro.2022.765068>
- Gee GW, Or D. Particle-Size Analysis. In *Methods of Soil Analysis, Part 4: Physical Methods*. 2018; <https://doi.org/10.2136/sssabookser5.4.c12>
- Grundy PR, Yeates SJ, Bell KL. Cotton production during the tropical monsoon season. I – The influence of variable radiation on boll loss, compensation and yield. *Field Crops Research*. 2020;254(4). <https://doi.org/10.1016/j.fcr.2020.107790>
- Hand LC, Snider JL, Roberts PM. Investigating the rain-free period of mepiquat chloride as affected by surfactant, rate, and interval between application and simulated rainfall. *Crop, Forage and Turfgrass Management*. 2023;9(1),1–8. <https://doi.org/10.1002/cft2.20214>
- Hu T, Liu Z, Jin D, Chen Y, Zhang X, Chen D. Effects of Growth Regulator and Planting Density on Cotton Yield and N, P, and K Accumulation in Direct-Seeded Cotton. *Agronomy*. 2023;13(2). <https://doi.org/10.3390/agronomy13020501>
- Jia Y, Yang B, Han Y, Wang G, Su T, Li X, Lei Y, Zhi X, Xiong S, Xin M, Li Y, Feng L. Enhanced Cotton Yield and Fiber Quality by Optimizing Irrigation Amount and Frequency in Arid Areas of Northwest China. *Agronomy*. 2024;14(2). <https://doi.org/10.3390/agronomy14020266>
- Keller C, Joshi S, Joshi T, Goldmann E, Riar A. Challenges for crop diversification in cotton-based farming systems in India: a comprehensive gap analysis between practices and policies. *Frontiers in Agronomy*. 2024;6, 1370878.
- Khan MA, Anwar S, Abbas M, Aneeq M, de Jong F, Ayaz M, Wei Y, Zhang R. Impacts of climate change on cotton production and advancements in genomic approaches for stress resilience enhancement. *Journal of Cotton Research*. 2025;8(1),17.
- Kızılsımsek M, Günaydın T, Akbay F. Determination of feed quality characteristics of some silage Maize (*Zea mays* L.) hybrids cultivated in eastern mediterranean conditions. *Turkish Journal of Field Crops*. 2024;29(1),46–53.
- Leal AJF, Piatí GL, Leite RC, Zanella MS, Osorio CRWS, Lima SF. Nitrogen and mepiquat chloride can affect fiber quality and cotton yield. *Revista Brasileira de Engenharia Agrícola e Ambiental*. 2020;24(4),238–243. <https://doi.org/10.1590/1807-1929/agriambi.v24n4p238-243>
- Lee JM, Snider JL, Roberts P, Hand LC, Culpepper AS, Pokhrel A, Chalise DP. The effect of pre-drought mepiquat chloride management on cotton sensitivity to drought during peak water demands. *Field Crops Research*. 2023;298. <https://doi.org/10.1016/j.fcr.2023.108969>
- Liang F, bin, Yang C, xun, Sui L, long, Xu S, zhen, Yao H, sheng, Zhang WF. Flumetralin and dimethyl piperidinium chloride alter light distribution in cotton canopies by optimizing the spatial configuration of leaves and bolls. *Journal of Integrative Agriculture*. 2020;19(7). [https://doi.org/10.1016/S2095-3119\(19\)62792-9](https://doi.org/10.1016/S2095-3119(19)62792-9)

- Liu S, Zuo D, Cheng H, He M, Wang Q, Lv L, Zhang Y, Ashraf J, Liu J, Song G. Cotton pedigree genome reveals restriction of cultivar-driven strategy in cotton breeding. *Genome Biology*. 2023;24(1). <https://doi.org/10.1186/s13059-023-03124-3>
- Luo H, Zhang Z, Wu J, Wu Z, Wen T, Tang F. Effects of mepiquat chloride and plant population density on leaf photosynthesis and carbohydrate metabolism in upland cotton. *Journal of Cotton Research*. 2023;6(1),1–16. <https://doi.org/10.1186/s42397-023-00157-8>
- Malima M, Kurt O, Hacikamiloglu MS. Quantifying the impact of environmental conditions on the effectiveness of mepiquat chloride in modulating canopy architecture, yield, and quality of drought-stressed cotton (*Gossypium hirsutum* L.). *Journal of Current Opinion in Crop Science*. 2025b;6(1),6–17.
- Malima M, Kurt O, Hacikamiloglu MS. Response to Reduced Doses of Mepiquat Chloride on Yield and Quality Characteristics of Cotton (*Gossypium hirsutum* L.) in the Mediterranean Region of Türkiye. *Akademik Ziraat Dergisi*. 2025a;14(1),105–114.
- Mangi N, Iqbal MS, Shuli F, Iqbal M, Alharthi B, Ma Q, Sarfraz Z, Jatoi G, Sun X. Empowering cotton breeding programs through the strategic exploration and exploitation of phenotypic diversity of genetic resources under climate change conditions. *Plant Stress*. 2024;13(3),100548. <https://doi.org/10.1016/j.stress.2024.100548>
- McLean EO. *Soil pH and Lime Requirement*. 1982; <https://doi.org/10.2134/agronmonogr9.2.2ed.c12>
- Meng L, Yu K, Wei Z, Li K, Dai J, Li F, Qi H, Sun L, Zhang L, Dong H, Lu Z, Xu D, Zhang M, Du M, Tian X, Li Z. High dosage of mepiquat chloride delays defoliation of harvest aids in cotton. *Industrial Crops and Products*. 2023;202. <https://doi.org/10.1016/j.indcrop.2023.116998>
- Murtza K, Ishfaq M, Akbar N, Hussain S, Anjum SA, Bukhari NA., Algarawi AM, Hatamleh AA. Effect of Mepiquat Chloride on Phenology, Yield and Quality of Cotton as a Function of Application Time Using Different Sowing Techniques. *Agronomy*. 2022;12(5). <https://doi.org/10.3390/agronomy12051200>
- Nelson DW, Sommers LE. Total carbon, organic carbon, and organic matter. In *Methods of Soil Analysis, Part 3: Chemical Methods*. 2018. <https://doi.org/10.2136/sssabookser5.3.c34>
- Olsen SR, Sommers LE. Phosphorus. In AL.;, Miller RH.;, & Keeney DR (Eds.), *Methods of soil analysis part 1: Chemical and Microbiology properties: Vol. Monograph no.9*. Second edition. 1982. pp. 403–430. America Society of Agronomy.
- Priyadarshini M, Kumar GS, Nagabhushanam U, Reddy KPC. Effect of Different Doses and Scheduling Time of Plant Growth Regulators and Defoliant on Growth and Yield of Cotton (*Gossypium hirsutum* L.) under High Density Planting System. *International Journal of Environment and Climate Change*. 2023;13(10). <https://doi.org/10.9734/ijecc/2023/v13i102888>
- Priyanka K, Sreerekha M, Lakshman K. Effect of plant growth regulators on growth and yield of HDPs Cotton. *Journal of Cotton Research and Development*. 2022;36(1):65–70.

- Reddy RA, Reddy KR, Hodges HF. Mepiquat chloride (PIX)-induced changes in photosynthesis and growth of cotton. *Plant Growth Regulation*. 1996;20(3). <https://doi.org/10.1007/bf00043305>
- Raphael JPA, Echer FR, Rosolem CA. Understanding fiber quality in field-grown shaded cotton: Nitrogen fertilization implications. *Field Crops Research*. 2024;317,109543.
- Reddy VR, Baker DN, Hodges HF. Temperature and Mepiquat Chloride Effects on Cotton Canopy Architecture. *Agronomy Journal*. 1990;82(2). <https://doi.org/10.2134/agronj1990.00021962008200020004x>
- Rosolem CA, Oosterhuis DM, De Souza FS. Cotton response to mepiquat chloride and temperature. *Scientia Agricola*. 2013;70(2),82–87. <https://doi.org/10.1590/S0103-90162013000200004>
- Saini DK, Impa SM, McCallister D, Patil GB, Abidi N, Ritchie G, Jaconis SY, Jagadish KSV. High day and night temperatures impact on cotton yield and quality—current status and future research direction. *Journal of Cotton Research*. 2023;6(1). <https://doi.org/10.1186/s42397-023-00154-x>
- Sharma A, Deepa R, Sankar S, Pryor M, Stewart B, Johnson E, Anandhi A. Use of growing degree indicator for developing adaptive responses: A case study of cotton in Florida. *Ecological Indicators*. 2021;124. <https://doi.org/10.1016/j.ecolind.2021.107383>
- Shi F, Li N, Khan A, Lin H, Tian Y, Shi X, Li J, Tian L, Luo H. DPC can inhibit cotton apical dominance and increase seed yield by affecting apical part structure and hormone content. *Field Crops Research*. 2022;282. <https://doi.org/10.1016/j.fcr.2022.108509>
- Singh K, Harinderpal S, Pankaj R, Kuldeep S, Sudhir KM. Manipulations of source sink relationships through mepiquat chloride for enhancing cotton productivity and monetary returns in north west India. *Journal of Cotton Research and Development*. 2017;31(1).
- Sreedasyam A, Lovell JT, Mamidi S, Khanal S, Jenkins JW, Plott C, Bryan KB, Li Z, Shu S, Carlson J. Genome resources for three modern cotton lines guide future breeding efforts. *Nature Plants*. 2024;10(6), 1039–1051.
- Thapliyal D, Verma S, Sen P, Kumar R, Thakur A, Tiwari AK, Singh D, Verros GD, Arya RK. Natural Fibers Composites: Origin, Importance, Consumption Pattern, and Challenges. *Journal of Composites Science*. 2023;7(12). <https://doi.org/10.3390/jcs7120506>
- Thavkar S, Thube S, Panchbhai P, Lavhe N, Pillai T, Shah V, Deshmukh V, Pandian TR, Fand B, Tenguri P. Evaluation of bio-efficacy of *Metarhizium anisopliae* against the pink bollworm *Pectinophora gossypiella* (Saunders), with insights into its colonization potential and insecticide compatibility. *Journal of Cotton Research*. 2025;8(1), 8.
- Thomas GW. (1982). Exchangeable Cations . In AL;, Miller RH;, & Keeney DR (Eds.), *Methods of soil analysis part 1: Chemical and Microbiology properties: Vol. Monograph No.9*. Second edition. 1982. pp. 159–165. America Society of Agronomy.
- Tlatlaa JS, Tryphone GM, Nassary EK. Improving Cotton Fiber Quality Through Strategic Sowing: Implications for Phosphorus Management from Experiments in Chato District, Tanzania. *Journal of Natural Fibers*. 2024;21(1), 2365352.

- Tlatlaa JS, Tryphone GM, Nassary E. K. Effects of sowing dates and phosphorus levels on cotton growth and yield: soil analysis and implications. *Frontiers in Sustainable Food Systems*. 2023a;7. <https://doi.org/10.3389/fsufs.2023.1298459>
- Tlatlaa JS, Tryphone GM, Nassary EK. Unexplored agronomic, socioeconomic and policy domains for sustainable cotton production on small landholdings: a systematic review. *Frontiers in Agronomy*. 2023b; 5:1281043. <https://doi.org/10.3389/fagro.2023.1281043>
- TSMS. *The State of the Türkiye's Climate in 2022*. 2023; https://www.mgm.gov.tr/eng/Yearly-Climate/State_of_the_Climate_in_Turkey_in_2022.pdf.
- TSMS. *The State of the Türkiye's Climate in 2023*. 2024. https://www.mgm.gov.tr/eng/Yearly-Climate/State_of_the_Climate_in_Turkey_in_2023.pdf
- Tung SA, Huang Y, Hafeez A, Ali S, Khan A, Souliyanonh B, Song X, Liu A, Yang G. Mepiquat chloride effects on cotton yield and biomass accumulation under late sowing and high density. *Field Crops Research*. 2018;215, 59–65. <https://doi.org/10.1016/j.fcr.2017.09.032>
- Ullah A, Shakeel A, Ahmed HGMD, Naeem M, Ali M, Shah AN, Wang L, Jaremko M, Abdelsalam NR, Ghareeb RY, Hasan ME. Genetic basis and principal component analysis in cotton (*Gossypium hirsutum* L.) grown under water deficit condition. *Frontiers in Plant Science*. 2022;13. <https://doi.org/10.3389/fpls.2022.981369>
- Wang Z, Li Y, Zhu Q, Tian L, Liu F, Zhang X, Sun J. Transcriptome Profiling Provides New Insights into the Molecular Mechanism Underlying the Sensitivity of Cotton Varieties to Mepiquat Chloride. *International Journal of Molecular Sciences*. 2022;23(9). <https://doi.org/10.3390/ijms23095043>
- Wu Y, Tang C, Zhang Y, Du M, Yang M, Tian J, Zhang W. Synergistic improvement of cotton yield and fiber quality in heat-deficient regions: Selecting varieties sensitive to mepiquat chloride and increasing planting density. *Industrial Crops and Products*. 2025;235, 121781.
- Zafar MM, Chattha WS, Khan AI, Zafar S, Subhan M, Saleem H, Ali A, Ijaz A, Anwar Z, Qiao F, Shakeel A, Seleiman MF, Wasonga DO, Parvaiz A, Razzaq A, Xuefei J. Drought and heat stress on cotton genotypes suggested agro-physiological and biochemical features for climate resilience. *Frontiers in Plant Science*. 2023;14. <https://doi.org/10.3389/fpls.2023.1265700>
- Zafar MM, Jia X, Shakeel A, Sarfraz Z, Manan A, Imran A, Mo H, Ali A, Youlu Y, Razzaq A, Iqbal MS, Ren M. Unraveling Heat Tolerance in Upland Cotton (*Gossypium hirsutum* L.) Using Univariate and Multivariate Analysis. *Frontiers in Plant Science*. 2022;12. <https://doi.org/10.3389/fpls.2021.727835>
- Zafar MM, Manan A, Razzaq A, Zulfqar M, Saeed A, Kashif M, Khan AI, Sarfraz Z, Mo H, Iqbal MS, Shakeel A, Ren, M. Exploiting agronomic and biochemical traits to develop heat resilient cotton cultivars under climate change scenarios. *Agronomy*. 2021;11(9). <https://doi.org/10.3390/agronomy11091885>
- Zhang J, Wang H, Feng D, Cao C, Zheng C, Dang H, Li K, Gao Y, Sun C. Evaluating the impacts of long-term saline water irrigation on soil salinity and cotton yield under plastic

film mulching: A 15-year field study. *Agricultural Water Management*. 2024;293. <https://doi.org/10.1016/j.agwat.2024.108703>

Zhang M, Cao H, Xi J, Zeng J, Huang J, Li B, Song S, Zhao J, Pei Y. Auxin Directly Upregulates GhRAC13 Expression to Promote the Onset of Secondary Cell Wall Deposition in Cotton Fibers. *Frontiers in Plant Science*. 2020;11. <https://doi.org/10.3389/fpls.2020.581983>

Zhang M, Zhang X, Zhang L, Zeng L, Liu Y, Wang X, He P, Li S, Liang G, Zhou W, Ai C. The stronger impact of inorganic nitrogen fertilization on soil bacterial community than organic fertilization in short-term condition. *Geoderma*. 2021;382. <https://doi.org/10.1016/j.geoderma.2020.114752>

Zhang Y, Yang Y, Lu X, Wang A, Xue C, Zhao M, Zhang J. The effects and interrelationships of intercropping on Cotton Verticillium wilt and soil microbial communities. *BMC Microbiology*. 2023;23(1). <https://doi.org/10.1186/s12866-023-02780-6>

Zhao W, Du M, Xu D, Lu H, Tian X, Li Z. Interactions of single mepiquat chloride application at different growth stages with climate, cultivar, and plant population for cotton yield. *Crop Science*. 2017;57(3). <https://doi.org/10.2135/cropsci2016.12.1008>

Zhao W, Yan Q, Yang H, Yang X, Wang L, Chen B, Meng Y, Zhou Z. Effects of mepiquat chloride on yield and main properties of cottonseed under different plant densities. *Journal of Cotton Research*. 2019;2(1), 1–10. <https://doi.org/10.1186/s42397-019-0026-1>

Zhu Y, Zhao M, Li T, Wang L, Liao C, Liu D, Zhang H, Zhao Y, Liu L, Ge X, Li B. Interactions between Verticillium dahliae and cotton: pathogenic mechanism and cotton resistance mechanism to Verticillium wilt. *Frontiers in Plant Science*. 2023;14. <https://doi.org/10.3389/fpls.2023.1174281>