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***Research Article* (*Araştırma Makalesi*)**

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Determination of the effect of plant growth regulators on agronomic characteristics of sweet corn by multivariate analysis

Tatlı mısırda bitki büyüme düzenleyicilerin agronomik özelliklere etkisinin çok değişkenli analizler ile belirlenmesi

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ABSTRACT

Objective: This study was conducted to determine the effects of gibberellic acid (GA_3) and sodium nitrophenol applications on agronomic traits in sweet corn.

Material and Methods: In the study designed as a factorial arrangement in a randomized block design, foliar applications of GA_3 (T1), sodium nitrophenol (T2), and GA_3 + sodium nitrophenol (T3) were applied to the plants.

Results: Plant growth regulators significantly improved the overall performance of sweet corn compared to the control. T3 treatment provided the highest values by increasing plant height by 30%, leaf area by 17%, cob diameter by 27%, cob yield by 12% and fresh cob yield by 22%. However, the effects of the treatments on cob length and seed number were limited. PCA revealed the significant effect of T3 treatment on vegetative traits such as plant height and leaf area, while correlation analysis showed that these traits had a strong positive relationship with fresh cob yield.

Conclusion: In sweet corn, these findings confirm the main contribution of vegetative development in yield increase and the high performance potential of the combined treatment. In conclusion, the combined application of GA_3 and sodium nitrophenol offers a promising approach for sustainable yield increase in sweet corn.

Keywords: Agronomic traits, gibberellic acid, plant growth regulators, sodium nitrophenol, sweet corn

ÖZ

Amaç: Bu çalışma, şeker mısırda gibberellik asit (GA_3) ve sodyum nitrofenol uygulamalarının agronomik özellikler üzerindeki etkilerini belirlemek amacıyla yürütülmüştür.

Materyal ve Yöntem: Tesadüf blokları deneme deseninde faktöriyel düzenlemeye göre tasarlanan çalışmada, bitkilere yapraktan GA_3 (T1), sodyum nitrofenol (T2) ve GA_3 + sodyum nitrofenol (T3) uygulamaları yapılmıştır.

Araştırma Bulguları: Bitki büyüme düzenleyicileri, kontrole kıyasla şeker mısırın genel performansını önemli ölçüde iyileştirmiştir. T3 uygulaması, bitki boyunu %30, yaprak alanını %17, koçan çapını %27, koçan randımanını %12 ve taze koçan verimini %22 oranında artırarak en yüksek değerleri sağlamıştır. Ancak koçan uzunluğu ve tane sayısı üzerinde uygulamaların etkisi sınırlı kalmıştır. PCA analizi, T3 uygulamasının bitki boyu ve yaprak alanı gibi vejetatif özellikler üzerindeki belirgin etkisini ortaya koyarken, korelasyon analizi bu özelliklerin taze koçan verimiyle güçlü bir pozitif ilişki içinde olduğunu göstermiştir.

Sonuç: Şeker mısırda, bu bulgular vejetatif gelişimin verim artışındaki temel katkısını ve kombine uygulamanın yüksek performans potansiyelini doğrulamaktadır. Sonuç olarak, GA_3 ve sodyum nitrofenolün kombine uygulaması şeker mısırda sürdürülebilir verim artışı için umut verici bir yaklaşım sunduğunu göstermektedir.

Anahtar sözcükler: Agronomik özellikler, gibberellik asit, bitki büyüme düzenleyiciler, sodyum nitrofenol, şeker mısır

INTRODUCTION

Sweet corn (*Zea mays* var. *saccharata*) is an agricultural crop distinguished by its high sugar content among corn species and holds substantial economic value worldwide. It serves as an important raw material for fresh consumption, the canning industry, and the broader food sector (Revilla et al., 2021). The genetic makeup of sweet corn is characterized by elevated sugar accumulation and reduced starch content compared to other corn varieties (Okumura et al., 2013). These attributes make sweet corn a popular choice in terms of both nutritional quality and flavour.

Sweet corn production in the world is approximately 1 million ha, production is approximately 9.7 million tons and yield is 9 tons ha^{-1}. Sugar corn production is highest in the USA (2.8 million tons), Mexico (1.1 million tons), Nigeria (793 thousand tons) and Indonesia (558 thousand tons) (FAO, 2023). The highest production is observed in the USA (2.6 million tons), followed by Mexico (1.1 million tons), Nigeria (776 thousand tons), and Indonesia (654 thousand tons) (FAO, 2021). In Türkiye, sweet corn is gaining significance both in agricultural production and the food industry. The country's climate and soil conditions provide favorable regions for sweet corn cultivation, particularly in the Mediterranean, Aegean, and Marmara regions (Eşiyok et al., 2004; Öktem & Öktem, 2006). Despite global production efforts, the supply of sweet corn does not fully meet market demand, one of the main major reasons being fort his is its relatively low yield potential (Laksono et al., 2018). In Türkiye, sweet corn production is subject to abiotic and biotic stress factors, including drought, high temperatures, and pest infestations (Öktem & Öktem, 2018). Particularly, irregular rainfall patterns and temperature fluctuations, which are intensifying due to climate change, can cause yield losses during critical developmental stages (IPCC, 2021). Therefore, implementing strategies that enhance yield and improve quality are critical to boosting farmers' income and supporting food security.

Plant growth regulators (PGRs) are chemical or biological substances used in agriculture to promote plant growth and regulate various physiological processes (Kumlay & Eryiğit, 2011). They are widely recognised as effective tools for increasing yield by influencing growth rate, flowering, fruit development, and stress tolerance (Taiz & Zeiger, 2010). A wide range of PGRs, including natural hormones and synthetic chemicals, can produce diverse outcomes depending on the plant species and application methods (Shahniza et al., 2020; Çakır et al., 2021; Mubarok et al., 2022). In sweet corn, the appropriate timing and dosage of PGR applications are critical for ensuring both plant health and economic profitability (Rademacher, 2015).

Gibberellic acid (GA_3) is one of the most well-known and extensively studied natural plant hormones. Gibberellins promote cell division and elongation, supporting physiological processes such as stem elongation, seed germination, and fruit development (Gupta & Chakrabarty, 2013; Algül et al., 2016). The use of GA_3 in agricultural practices has been investigated extensively, particularly for its potential to enhance yield and improve stress resistance. Its positive effects on cob size and seed development in sweet corn are among the key findings supporting its practical application (Al-Shaheen & Soh, 2018; Shahniza et al., 2020; Sopacua et al., 2022). However, the effects of GA_3 can vary depending on the species of plant, the environmental conditions, and the concentrations at which it is applied (Hedden & Thomas, 2016). Nitrophenols constitute a group of synthetic plant growth regulators, with derivatives such as 4-nitrophenol reported to enhance photosynthetic rates by modulating plant metabolism (Batool et al., 2023). These compounds can support root and stem development and improve nutrient uptake through auxin-like effects (Amin, 2007; Fang et al., 2023). Although the precise mechanism of action of nitrophenol compounds has not been fully elucidated, there is growing evidence suggesting that they activate antioxidant defense systems, thereby increasing plant resilience to abiotic stress (Djanaguiraman et al., 2004; Iwaniuk et al., 2023). While the agricultural use of nitrophenols is not yet as widespread as that of GA_3, they show potential as alternative growth regulators. However, research into the effects of nitrophenols on sweet corn is limited (Chen et al., 2019).Research exploring the combined effects of growth regulators such as GA_3 and nitrophenols, on sweet corn is still scarce. Although GA_3 has been shown to enhance growth and yield parameters in sweet corn, the impact of nitrophenols remains largely unexplored.. This study therefore aimed to determine the effects of foliar application GA_3 and nitrophenol on the yield and yield components of sweet corn.

MATERIALS and METHODS

Materials

The research was conducted on Isparta University of Applied Sciences land over two consecutive growing seasons, in 2020 and 2021. A Kompozit sweet corn cultivar obtained from a private company was used as the experimental material. In addition, GA_3 ($C_{22}H_{26}O_8$; CAS No: 1373154-68-7) and sodium nitrophenol (a mixture of 9 g/L sodium p-nitrophenolate, 6 g/L sodium o-nitrophenolates, and 3 g/L sodium 5-nitroguaiacolate) were used as synthetic plant growth regulators. Gibberellic acid and sodium nitrophenol chemicals were supplied by Doğal Kimyevi Maddeler ve Zirai İlaçlar San. ve Tic. AŞ.

Climate and soil characteristics of the research site

Significant differences were observed in climatic variables (precipitation, humidity, and temperature) during the sweet corn growing periods of 2020 and 2021. In 2020, total precipitation was high in May but decreased considerably from June to September, humidity levels declined from May to July, while temperature increased until June and remained stable in July-August. In 2021, total precipitation peaked in May but dropped significantly in June-July; humidity also decreased from May to July, whereas temperature reached its highest value in June and fluctuated during the subsequent months. Overall, more stable temperature and humidity conditions were recorded in 2020, while 2021 experienced intense rainfall events and greater temperature fluctuations (Figure 1).

The experiment was conducted on soils with similar characteristics in both years. Soil sampling was done at a depth of 0-30 cm and before planting. Soil samples, collected from the experimental area exhibited a clay-loam texture, low organic matter content (1.5%), high lime content (28.7%), a pH of 7.66, low phosphorus content (23.5 mg kg^{-1}), and high potassium content (176.2 mg kg^{-1}).

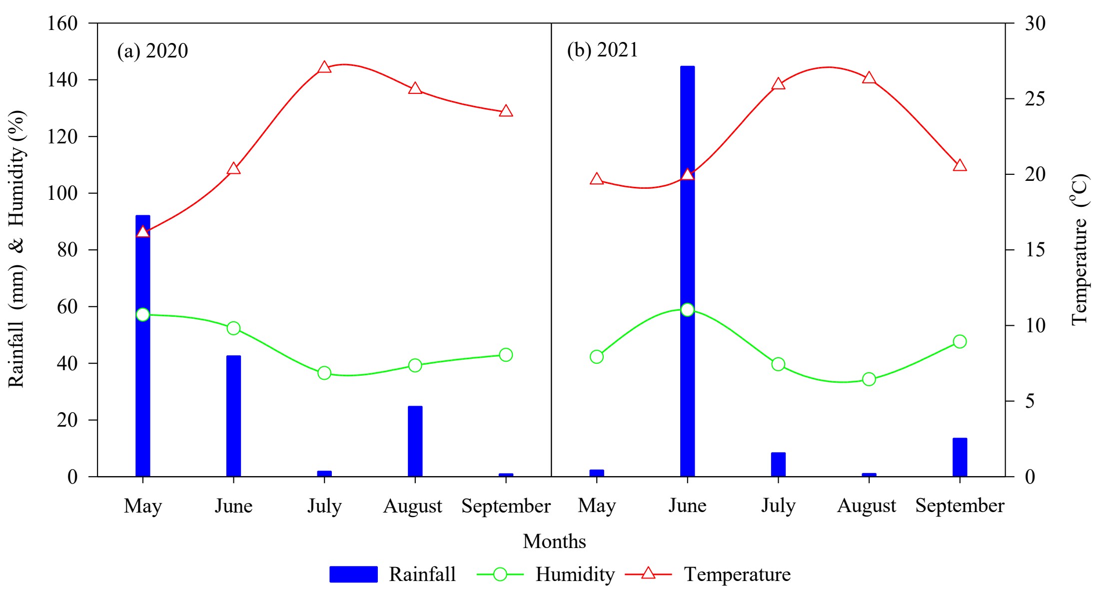


Figure 1. Climate data for the years in which the trial was conducted (2020-2021).

Şekil 1. Denemenin yürütüldüğü yıllara (2020-2021) ait iklim verileri.

Methods

The experiment was conducted in a randomized complete block design with a factorial arrangement and three replications. Foliar applications included control (pure water), GA_3 application, (100 mg L^{-1} ,T_1), sodium nitrophenolate application, (20 mg L^{-1}, T_2), and their combination (GA_3 + sodium nitrophenolate) (T_3). Each block contained four plots, totaling 12 plots overall. Sweet corn seeds were manually sown during the first week of May (3 May and 7 May, respectively) in both years, at a planting density of 70 × 20 cm, with four rows per plot (plot area: 14 m², 2.8 m × 5 m). Two seeds were sown per hill to optimize plant density, and following emergence, plants were thinned to one per hill at the 1-2 leaf stage (V1-V2). At sowing, 8 kg $da^{-1}$of P_2O_5 and 10 kg da^{-1} N were applied; an additional 10 kg da^{-1} of nitrogen was top-dressed when plants reached a height of 30-40 cm (Akgün et al., 2021). GA_3 (T1), sodium nitrophenol (T2), GA_3 + sodium nitrophenol (T3), and control (pure water) treatments were applied by spraying the aerial parts of the plants with a knapsack sprayer at a volume of 40 L ha^{-1} at the 6-leaf stage (BBCH 16). Drip irrigation was applied based on soil moisture status following planting, depending on climatic conditions. Weed control was performed manually when necessary.

At the end of the study, each plot was harvested separately during the milk maturity stage (BBCH 73-75), taking into account the physiological maturity of the plants. The effective harvest area was defined by excluding border rows and a 50 cm margin at the plot ends. From each harvest area, 10 plants were randomly selected for measurements. Plant height (cm), leaf area (cm²), cob length (cm), cob diameter (mm), seed number in cob, fresh cob yield (kg da^{-1}), and cob filling ratio (%) were determined.

Data analysis

The data obtained from the experiments were analysed usinganalysis of variance (ANOVA) based on a factorial arrangement within a randomized complete block design, withStatistix software package (version 8.1) being used for this analysis . Differences in means were determined using the least significant difference (LSD) test. To assess the relationships among the studied traits and the interactions between treatments and years, correlation matrices and principal component analysis (PCA) biplot graphs were generated using R software (version 4.3.2) andthe "PerformanceAnalytics", "psych", "ggplot2", "gridExtra", "ggbiplot", and "corrplot" packages.

RESEARCH RESULTS

In this study, the effects of gibberellic acid (GA_3) and sodium nitrophenolate applications on the yield and yield components of sweet corn were evaluated during the 2020 and 2021 growing seasons. The results revealed significant differences in plant height, leaf area, cob diameter, cob length, cob filling ratio, seed number in cob, and fresh cob yield depending on both the year and the applied treatments (Table 1;2). These findings indicate that plant growth regulators can play an effective role in the developmental processes of sweet corn, particularly in yield enhancement.

Plant height exhibited significant variation (p<0.01) between the years. The mean plant height was 213 cm in 2020, whereas it decreased to 159.43 cm in 2021. This reduction suggests that temperature fluctuations and irregular rainfall patterns observed in 2021 negatively affected plant development. In contrast, the more favorable climatic conditions in 2020 provided better support for sweet corn growth. Among the applications made in the study, it was found that the T3 group (GA_3 + sodium nitrophenolate) increased plant height by 30.6% compared to the control (Tables 1 & 2). A significant year × treatment interaction was detected for plant height (p<0.01) (Table 1).

In 2020, the highest plant height was achieved with T3 (237.87 cm), followed by T2 (213.87 cm) and T1 (201.87 cm), while the control group showed the lowest value (177.47 cm). In 2021, plant height declined across all treatments. However, T3 again recorded the highest value (175.91 cm), followed by T2 (167.20 cm), T1 (162.70 cm), and the control (130.47 cm). In 2020, the differences between treatments were more pronounced, with T3 maintaining a clear superiority over the others (Figure 2). In 2021, plant height decreased, and the differences between treatments became narrower due to adverse environmental conditions. These results suggest that the effectiveness of plant growth regulators can vary according to environmental factors and they tend to be more pronounced under favorable climatic conditions, as observed in 2020. Similarly, leaf area was significantly affected by the year. While the mean leaf area was 563.75 cm² in 2020, it decreased to 457.67 cm² in 2021 ($p<0.01$). The lower leaf area in 2021 indicates that environmental stresses suppressed leaf development. Among the applications used in the study, the T3 group (GA_3 + sodium nitrophenolate) and the T2 group (sodium nitrophenol) increased the leaf area by 17.3% and 13.1%, respectively, compared to the control (Table 2). A significant year × treatment interaction was also observed for leaf area (Table 1). The interaction effect on leaf area is clearly illustrated in Figure 2. In 2020, T3 achieved the highest leaf area (600.13 cm²), followed closely by T2 (596.67 cm²). T1 exhibited an intermediate value (541.00 cm²), whereas the control group had the lowest leaf area (517.50 cm²). In 2021, leaf area decreased across all treatments. T3 recorded the highest value (466.33 cm²), followed by T2 (419.67 cm²), T1 (414.67 cm²), and the control (410.00 cm²). These findings suggest that in 2020, T3 and T2 treatments substantially promoted leaf development, leading to greater differences compared to the control. However, environmental stress factors in 2021 caused a general reduction in leaf area, minimisingthe differences between treatments (Figure 2).

When cob diameter was analyzed across years, it was found to be 5.04 cm in 2020 and 4.89 cm in 2021 ($p<0.05$). This slight decrease indicates that climatic conditions influenced cob development. Among the applications made in the study, the T3 group (GA_3 + sodium nitrophenolate) increased the cob diameter by 27% compared to the control. The T1 (4.72 cm) and T2 (4.88 cm) treatments produced better results than those of the control ($p<0.01$) (Table 1;2). The contribution of the combined treatment (T3) to cob development was notable. A significant year × treatment interaction was observed for cob diameter (Figure 2). In 2020, the highest cob diameter was obtained from the T3 treatment (6.07 cm), followed by T2 (4.73 cm) and T1 (4.53 cm), while the control group recorded the lowest diameter (4.32 cm). In 2021, cob diameters generally declined; however, the T3 treatment maintained the highest value (5.45 cm), followed by the T2 treatment (4.90 cm). The T1 treatment and the control group both had the same value (4.37 cm). These results suggest that the combined application was particularly effective in enhancing cob diameter under favourable environmental conditions in 2020. However, in 2021, cob diameter values decreased across all treatments, and the differences between them became less pronounced due to environmental stress factors.

Table 1.Analysis of variance table for agronomic traits of sweet corn according to year and treatments

Çizelge 1. *Tatlı mısırın agronomik özellikleri için yıllara ve uygulamalara göre varyans analizi tablosu*

Source	DF	Plant height [1]	Leaf area	Cob diameter	Cob length	Cob yield	Seed number in cob	Fresh cob yield
Block	2	15.6	966.3	0.01	1.28	17.04	3352	17940
Year (Y)	1	17216.3	67522.0	0.13	13.55	42.67	179363	137751
App. (A)	3	2477.8	8310.2	1.72	1.52	55.61	19228	99834
Y x A	3	178.6	224.4	0.12	1.54	1.44	3833	8937
Error	14	12.6	736.8	0.02	0.65	12.14	6172	19723
CV		1.91	5.31	2.76	4.10	5.45	13.06	7.89

1: Mean squared values of traits; DF: Degrees of freedom

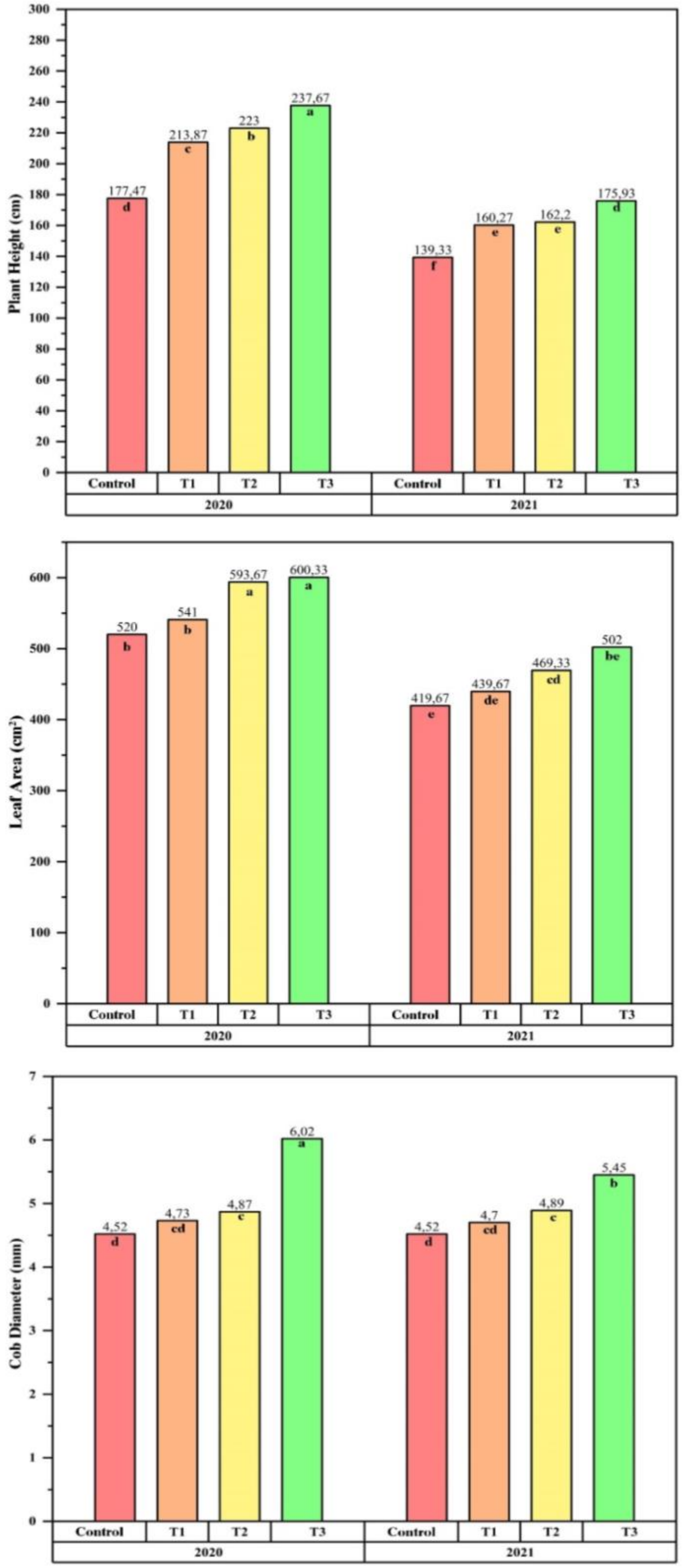


Figure 2. Year and treatment interaction for plant height, leaf area and cob diameter traits in sweet corn.

Şekil 2. *Tatlı mısırda bitki boyu, yaprak alanı ve koçan çapı özellikleri için yıl ve uygulama interaksiyonu.*

Table 2. Averages of agronomic traits of sweet corn according to year and treatments

Çizelge 2. *Tatlı mısırın yıllara ve uygulamalara göre agronomik özelliklerinin ortalamaları*

Source	Plant Height (cm)	Leaf Area (cm²)	Cob Diameter (cm)	Cob Length (cm)	Cob Performance (%)	Seed Number in Cob	Fresh Cob Yield (kg da⁻¹)
Years							
2020	213.00 a[1]	563.75 a	5.04 a	20.43 a	65.25	687.87 a	1845.2 a
2021	159.43 b	457.67 b	4.89 b	18.93 b	62.58	514.97 b	1716.2 b
LSD	3.11	23.76	0.12	0.7	3.05	68.78	122.97
F-value	1363.62**	91.65**	6.77*	20.75**	3.52 ns	29.06**	5.06*
Treatments							
Control	158.40 d	469.83 b	4.52 c	18.93	59.83 b	535.24	1595.2 c
T1	187.07 c	490.33 b	4.72 b	19.94	63.66 ab	580.89	1727.2 bc
T2	192.60 b	531.50 a	4.88 b	19.96	65.16 a	621.83	1861.1 ab
T3	206.80 a	551.17 a	5.74 a	19.90	67.00 a	667.72	1939.3 a
LSD	4.39	33.61	0.17	1.00	4.31	97.28	173.90
F-value	196.26**	11.28**	91.13**	2.33 ns	4.58*	3.12 ns	6.98**
Interaction (Year × Treatment)							
F-value	14.15**	7.01**	6.30**	2.37 ns	0.02 ns	0.62 ns	0.45 ns

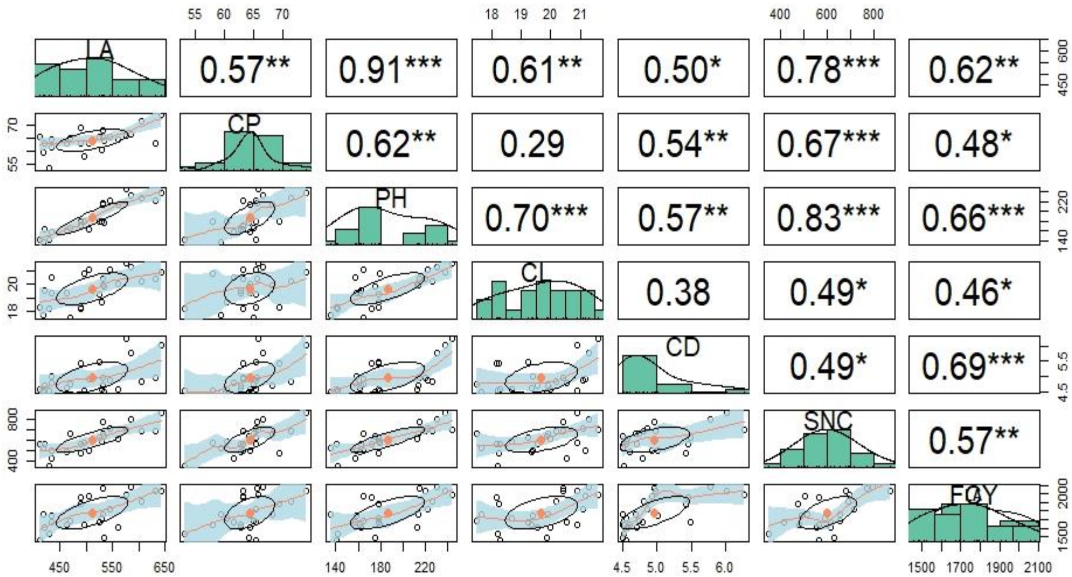
**: *p*≤0.01; *: *p*≤0.05; ns: non-significant; [1]Different letters (a, b, c, d) next to means within the same column indicate significant differences according to LSD test.

In terms of cob length, a decrease was observed from 20.43 cm in 2020 to 18.93 cm in 2021 ($p<0.01$), reflecting the influence of environmental factors over time. However, no statistically significant differences were found among treatments. The control (18.93 cm), T1 (19.94 cm), T2 (19.96 cm), and T3 (19.90 cm) treatments produced statistically similar results. Additionally, no significant year × treatment interaction was detected for cob length (Table 1). Cob performance showed no significant change over the years, with values calculated at 65.25% in 2020 and 62.58% in 2021. This suggests that climatic conditions had a limited effect on this parameter. Of the treatments used in the study, the T3 group (GA_3 + sodium nitrophenolate) and the T2 group (sodium nitrophenol) increased the cob performance values by 12% and 8.9%, respectively, compared to the control ($p<0.01$). No significant year × treatment interaction was observed for cob performance, indicating that the effects of the treatments were consistent across both years (Table 1).

The mean seed number in cob was 687.87 in 2020 and 514.97 in 2021 ($p<0.01$), suggesting that environmental stress negatively affected grain formation in 2021. Of the treatments, T3 (GA_3 + sodium nitrophenolate) produced the highest number of seeds per cob (667.72), howener, no statistically significant differences were observed among the control (535.24), T1 (580.89), and T2 (621.83) treatments (Table 1). These results suggest that the application of growth regulators had a limited effect on increasing the seed number per cob.

Fresh cob yield was determined as 1845.2 kg da^{-1} in 2020 and 1716.2 kg da^{-1} in 2021 ($p<0.05$), highlighting the influence of annual environmental variations on yield performance. Of the treatments applied in the study, the T3 group (GA_3 + sodium nitrophenolate) (1939.3 kg da^{-1}), increased the cob diameter by 21% compared to the control (1595.2 kg da^{-1}) ($p<0.01$). The T2 (1861.1 kg da^{-1}) and T1 (1727.2 kg da^{-1}) treatments also resulted in higher yields than the control. The positive impact of the combined treatment (T3) on fresh cob yield was clearly evident (Table 1).

The correlation analysis of agronomic traits revealed significant relationships (Figure 3). The strongest positive correlation was observed between leaf area and plant height (r=0.91, $p<0.01$), indicating that an increase in leaf area directly supports taller plant growth. Similarly, strong positive correlations were found between plant height and both fresh cob yield (r=0.66, p<0.01), and between plant height and cob diameter (r=0.70, p<0.01). In contrast, cob length exhibited weak correlations with other traits, such as fresh cob yield (r=0.29), suggesting that cob length is influenced by genetic and environmental factors. A moderate positive correlation was also observed between cob performance and fresh cob yield (r=0.48, p<0.05), highlighting the contribution of cob filling to overall yield potential. Overall, leaf area and plant height appeared to play a key role in determining the fresh cob yield of sweet corn, while cob length and seed number per cob were less responsive to the treatments.



LA: Leaf area; CP: Cob Performance; PH: Plant height; CL:Cob Length; CD: Cob Diameter; SNC: Seed Number in Cob; FGY: Fresh Cob Yield

Figure 3. Correlation matrix of relationships between agronomic traits in sweet corn.

Şekil 3. Tatlı mısırda agronomik özellikleri arasındaki ilişkilerin korelasyon matrisi.

A principal component analysis (PCA) was conducted to further evaluate the effects of GA_3 and sodium nitrophenolate treatments on agronomic traits further (Figure 4). Two biplot graphs were generated: the first illustrating variation between years (Figure 4a) and the second showing variation between treatments (Figure 4b). In the PCA, the first principal component (PC1) explained 65.7% of the total variation, while the second principal component (PC2) explained 11.6%, together accounting for 77.3% of the cumulative variation.

In the year-based biplot (Figure 4a), the data points for 2020 (orange ellipse) clustered on the right side, while those for 2021 (yellow ellipse) clustered on the left. This separation suggests that year-specific environmental conditions caused significant variation in the agronomic traits of sweet corn. Parameters such as plant height (PH), leaf area (LA), cob length (CL), cob diameter (CD), seed number in cob (SNC), and fresh cob yield (FCY) were associated with the 2020 cluster, as indicated by the orientation of their vectors. In particular, the long vectors of plant height and leaf area indicate their dominant influence on the variation in 2020. Conversely, 2021 was associated with lower values in most traits, likely due to temperature fluctuations and irregular precipitation patterns. The cob performance (CP) vector was positioned close to both years, suggesting that this trait was less sensitive to annual environmental variations.

In the treatment-based biplot (Figure 4b), the T3 treatment (purple ellipse) was positioned on the right, while the control group (light pink ellipse) was positioned on the left. T1 (light green ellipse) and T2 (light blue ellipse) were distributed between these extremes. This distribution highlights the superior performance of T3 across multiple agronomic traits. The vectors for plant height, leaf area, cob diameter, and fresh cob yield were oriented towards the T3 ellipse, confirming its dominant role in improving these parameters. In contrast, the vectors for cob length and seed number in cob were shorter and located closer to the control and T1 groups, indicating that these traits were less affectedby the treatments and more influenced bygenetic or the environment. factors. The cob performance vector was located between T2 and T3, emphasising the contribution of sodium nitrophenolate-containing treatments to cob filling. Overall, the synergistic effect of the T3 treatment enhanced the vegetative and generative development of sweet corn, resulting in superior agronomic performance.

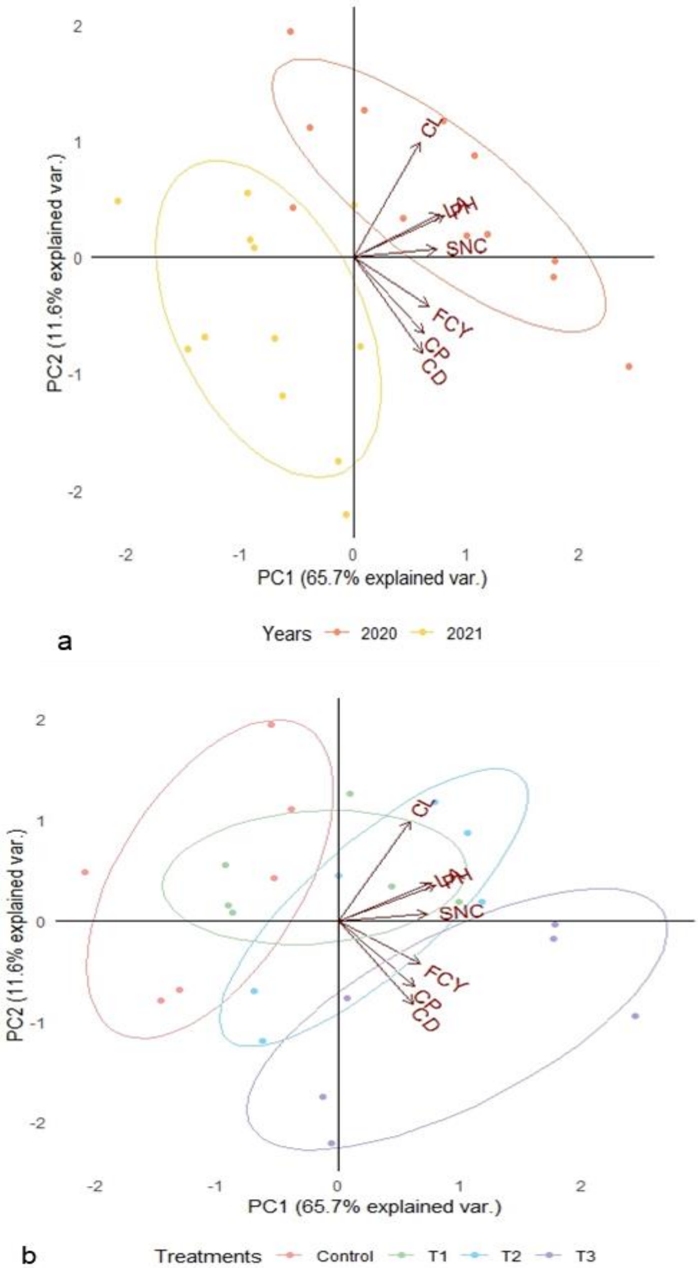


Figure 4. PCA-Biplot plot of agronomic traits for years (a) and treatments (b) in sweet corn.

Şekil 4. *Tatlı mısırda agronomik özelliklerin yıllar (a) ve uygulamalar (b) için PCA-Biplot grafiği.*

DISCUSSION

This study evaluated the effects of gibberellic acid and sodium nitrophenol applications on the yield and yield components of sweet corn in 2020 and 2021. The findings revealed that both environmental conditions and plant growth regulators both play a crucial role in the developmental processes of sugar maize development; significant differences were observed in parameters such as plant height, leaf area, cob diameter and fresh cob yield.

The parameters examined in this study, including plant height, leaf area, cob diameter, cob length, number of seeds per cob, and fresh cob yield of sweet corn exhibited higher mean values in 2020 compared to 2021. For instance, plant height decreased from 213 cm in 2020 to 159.43 cm in 2021 (p<0.01). Similarly, leaf area declined from 563.75 cm² to 457.67 cm², cob diameter from 5.04 cm to 4.89 cm, cob length from 20.43 cm to 18.93 cm, seed number in cob from 687.87 to 514.97, and fresh cob yield from 1845.2 kg da^{-1} to 1716.2 kg da^{-1}. These reductions are thought to be due to environmental factors encountered in 2021, particularly temperature fluctuations and irregular rainfall patterns (Figure 1). Öktem and Öktem (2018) reported that drought stress negatively affects the yield of sweet corn in the semi-arid regions of Türkiye. Furthermore, the IPCC (2021) report highlights that temperature increases and changes in precipitation regimes induced by climate change can lead to yield losses during crop development stages. In addition, Özata (2019) found that the average plant height of sweet corn genotypes ranged from 203.1 to 310.6 cm, cob diameter from 4.58 to 4.89 cm, cob length from 20.8 to 22.3 cm, and fresh cob yield from 1319.6 to 2423.8 kg da^{-1} across two different locations. The researcher emphasised the critical importance of genotype and environmental factors in sweet corn cultivation and noted that genotype × environment interactions have a significant impact on yield performance. Many researchers have reported that the yield and yield components of sweet corn vary depending on the genotype (Atakul, 2021; Ağaçkesen & Öktem, 2022; Temiz & Gökmen, 2023), environmental conditions where cultural practices (Eşiyok et al., 2004; Uçak et al., 2016), and where cultivation is practiced (Karaman et al., 2021; Akgün et al., 2023; Kılınç et al., 2023).

The effects of plant growth regulators on sweet corn revealed significant differences among the treatments, clearly demonstrating the potential of chemical agents used during plant development. The T3 treatment, produced the highest values for parameters such as plant height (206.80 cm), leaf area (551.17 cm²), cob diameter (5.74 cm), cob performance (67.00%), and fresh cob yield (1939.3 kg da^{-1}) were obtained compared to other treatments. In contrast, the control treatment exhibited the lowest values across all traits. These results indicate that plant growth regulators play an important role in supporting both vegetative and generative development in sweet corn. The positive effect of GA_3 on vegetative growth parameters such as plant height and cob diameter, is thought to result the physiological mechanisms of gibberellins that promote cell division and elongation. Gibberellins, lead to a marked increase in plant height by enhancing stem elongation and increasing cell wall flexibility (Hedden & Thomas, 2016). Additionally, the effect of GA_3 on cob diameter is associated with its promotion of cell growth in meristematic tissues, thereby supporting cob development (Srivastava, 2002). These findings support the potential of GA_3 in optimizing vegetative growth in sweet corn. For instance, Rademacher (2015) reported that GA_3 accelerates plant growth in agricultural applications, enhancing yield, and particularly improving cob development in crops such as maize. Similarly, Mishra et al. (2020) found that the application of GA_3 alongside standard fertilization strategies was effective in increasing cob diameter and the number of seeds per cob in sweet corn.

Sodium nitrophenolate improves the photosynthetic rate by enhancing carbon assimilation, thereby increasing the plant's energy production capacity (Chen et al., 2019). This promotes the expansion of leaf area, enabling the plant to capture more light energy. Application of sodium nitrophenolate application has been shown to increase plant height (Dobromilska et al., 2008), as well as leaf development and leaf number (Djanaguiraman et al., 2009). Furthermore, there is evidence that sodium nitrophenolate enhances plant resistance of plants to abiotic stress conditions by activating antioxidant systems (Zhang et al., 2015). In the present study, the significant increases observed in traits such as plant height, leaf area, cob performance, and fresh cob yield in the T2 treatment compared to the control group support this mechanism. During the vegetative growth phase of maize, the application of sodium nitrophenolate enhances nitrogen uptake and metabolic processes (Amin, 2007), and its use has been found to promote maize growth (Michalski et al., 2008).

The superior performance of the T3 treatment across all parameters is attributed to the synergistic effects of GA_3 and sodium nitrophenolate. While GA_3 promoted vegetative growth, sodium nitrophenolate optimized photosynthesis and metabolic processes, supporting generative development. This combination improved both biomass production and reproductive organ development. For instance, the increase in fresh cob yield observed in T3 (1939.3 kg da^{-1}) compared to the control group (1595.2 kg da^{-1}) demonstrates the economic significance of this synergistic effect. Furthermore, the success of T3 in improving cob diameter (5.74 cm) and cob performance (67.00%) suggests that this application could be an effective strategy for enhancing sweet corn product quality. A similar synergistic effect was reported by Kumar et al. (2020), who found that the combined use of GA_3 and other growth regulators improved both yield and quality parameters in maize. Additionally, sodium nitrophenolate application has been shown to strongly inhibit IAA oxidase, which is responsible for regulating auxin activity, thereby promoting growth (Szparaga et al. 2018). Yao et al. (2023) is reported beneficial effect of combination of GA3 + sodium nitrophenolate who suggested that it has a promising application in improving plant growth. El-Fouly et al. (2014) found that low and medium concentrations of combination of GA3 + sodium nitrophenolate increased including chlorophylls, carotenoids, and leaves content of N, P and K on *Ficus deltoidea* seedlings with growth and chemical compositions.

Othman et al. (2024) compared different combination of GA3 + sodium nitrophenolate applications in jackfruit fruits and stated that it showed superior performance in terms of plant height, number of leaves per plant, stem diameter, fresh and dry weight of the plant, number of roots, and leaf area. In particular, combination of GA3 + sodium nitrophenolate was shown to have a positive effect on certain mechanisms that regulate plant growth and development. Additionally, GA3 was reported to promote apical dominance, increase growth, and play a beneficial role in physiological plant's functions. In this study, it is believed that the combination improved these characteristics, resulting in an increase in leaf area and, consequently, an increase in yield and yield components.

In conclusion, the combination of GA_3 and sodium nitrophenolate was found to be more effective as it targets different physiological processes in sweet corn. The vegetative growth-promoting effects of GA_3, combined with the enhancement of photosynthesis and stress tolerance by sodium nitrophenolate, optimised both plant development and yield under the T3 treatment. These findings emphasise the potential of plant growth regulators as strategic tools in sweet corn production, with combined applications offering significant promise for enhancing yield and quality.

CONCLUSION

This study examined the effects of GA_3 and sodium nitrophenolate applications on agronomic traits of sweet corn through multivariate analyses conducted over the 2020 and 2021 growing seasons. The T3 treatment (combination of GA_3 and sodium nitrophenolate) achieved the highest values for key parameters, including plant height (206.80 cm), leaf area (551.17 cm^2), cob diameter (5.74 mm), cob performance (67.00%), and fresh cob yield (1939.3 kg da^{-1}), thereby significantly improving both yield and its components. In contrast, cob length and seed number in cob remained unaffected by the treatments, suggesting the prevailing influence of genetic and environmental factors. Favorable climatic conditions in 2020 contributed to enhanced performance, whereas environmental stresses such as temperature fluctuations and irregular precipitation in 2021 led to marked reductions. A significant year × treatment interaction was detected for plant height, leaf area, and cob diameter, with the superiority of T3 being more pronounced under the favorable conditions of 2020, whereas differences between treatments diminished in 2021. These findings underscore that the effectiveness of growth regulators is closely modulated by environmental factors, and highlight the potential of combined applications to enhance yield performance under variable conditions. In the study, the combined use of combination of GA3 + sodium nitrophenolate promotes plant yield and yield component development due to its synergistic effect on plants. Moreover, future longitudinal studies are warranted to better elucidate the impacts of climate change and to develop resilient and sustainable production strategies for sweet corn cultivation.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions

Concept and design of the study: RK; sample collection: RK, CT; data analysis and interpretation: RK, CT; statistical analysis: RK, CT; manuscript writing: RK, CT.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this study.

Ethical Statement

We declare that ethical approval was not required for this research.

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REFERENCES

Ağaçkesen, M. N. & A. Öktem, 2022. Farklı gelişme dönemlerinde yapılan hasadın tatlı mısırın (*Zea mays* L. *saccharata* Sturt) tane verimi ve verim unsurlarına etkisi. Harran Tarım ve Gıda Bilimleri Dergisi, 26 (4): 432-442. https://doi.org/10.29050/harranziraat.1186782

Akgün, İ., C. Türkay, R. Karaman & A. Kocabaş, 2023. Tatlı mısırda (*Zea mays saccharata* Sturt.) azotlu gübre çeşit ve dozlarının koçan verimi ve bazı kalite özellikleri üzerine etkisi. Türk Bilim ve Mühendislik Dergisi, 5 (2): 66-73. https://doi.org/10.55979/tjse.1340257

Akgün, İ., R. Karaman & A. Şener, 2021. Şeker mısırında farklı organik materyal ve azot uygulamalarının koçan verimi ve bazı agronomik özellikler üzerine etkisi. Anadolu Tarım Bilimleri Dergisi, 36 (3): 365-375. https://doi.org/10.7161/omuanajas.902843

Al-Shaheen, M.R. & A. Soh, 2018. The effect of water deficit and gibberellic acid on growth, productivity of corn (*Zea mays* L.). Journal of Advanced Research in Agriculture Science & Technology, 1 (1): 52-56.

Algül, B.E., F.E. Tekintaş & G. G. Dalkılıç, 2016. Bitki büyüme düzenleyicilerinin kullanımı ve içsel hormonların biyosentezini arttırıcı uygulamalar. Adnan Menderes Üniversitesi Ziraat Fakültesi Dergisi, 13 (2): 87-95. https://doi.org/10.25308/aduziraat.294100

Amin, A.A., 2007. Physiological response of two hybrids of yellow maize to foliar application of atonik and paclobutrazol. Journal of Plant Production, 32 (4): 2527-2541.

Atakul, Ş., Ş. Kahraman & S. Kılınç, 2021. Ana ürün koşullarında bazı şeker mısır genotiplerinin verim ve verim unsurlarının belirlenmesi. International Journal of Eastern Mediterranean Agricultural Research, 4 (1): 32-39.

Batool, Z., M. Ishfaq, N. Akbar, U. Zulfiqar, S.A. Anjum, M. Shafiq & A. Aziz, 2023. Exogenous application of Atonik (sodium nitrophenolate) under skip irrigation regimes modulated the physiology, growth and productivity of *Zea mays* L. Archives of Agronomy and Soil Science, 69 (12): 2325-2339. https://doi.org/10.1080/03650340.2022.2152011

Chen, H., Y. Zhang, J. Li, P. Zhang & N. Liu, 2019. Preparation of pickling-reheating activated alfalfa biochar with high adsorption efficiency for p-nitrophenol: characterization, adsorption behavior, and mechanism. Environmental Science and Pollution Research, 26: 15300-15313.

Çakır, M., A. Yıldırım, C. Çelik & M. Esen, 2021. Farklı bitki büyümeyi düzenleyici maddelerin Jeromine elma çeşidinde kalite ve biyokimyasal içerikleri üzerine etkisi. Anadolu Tarım Bilimleri Dergisi, 36 (3): 478-487. https://doi.org/10.7161/omuanajas.936081

Djanaguiraman, M., D.D. Devi, J.A. Sheeba, U. Bangarusamy & R.C. Babu, 2004. Effect of oxidative stress on abscission of tomato fruits and its regulation by nitrophenols. Tropical Agricultural Research, 16: 25-36.

Djanaguiraman, M., J. Annie Sheeba, D. Durga Devi & U. Bangarusamy, 2009. Cotton leaf senescence can be delayed bynitrophenolate spray through enhanced antioxidant defence system. Journal of Agronomy and Crop Science. 195 (3): 213-224. https://doi.org/10.1111/j.1439-037X.2009.00360.x

Dobromilska, R., M. Mikiciuk & K. Gubarewicz, 2008. Evaluation of cherry tomato yielding and fruit mineral composition after using of Bio-algeen S-90 preparation. Journal of Elementology, 13 (4): 491-499.

El-Fouly, S. Amal, Abdel-Moneim, M. Azza & E. Ibrahim, Hanan 2014. Response of the slowgrowing mistletoe fig (*Ficus deltoidea* jack.) plant to fertilization treatments and growth activator 1. The liquid commercial product of nitrophenolates. Scientific Journal Flowers & Ornamental Plants, 1(1):17-24.

Eşiyok, D., M.K. Bozokalfa & A. Uğur, 2004. Farklı lokasyonlarda yetiştirilen şeker mısır (*Zea mays* L. var. *saccharata*) çeşitlerinin verim kalite ve teknolojik özelliklerinin belirlenmesi. Ege Üniversitesi Ziraat Fakültesi Dergisi, 41 (1): 1-9.

Fang, S., J. Li, W. Zheng, Z. Liu, H. Feng & Y. Zhang, 2023. Effects of compound sodium nitrophenol on microspore embryogenesis and plantlet regeneration in flowering Chinese cabbage (*Brassica campestris* L. ssp. *chinensis* var. *utilis* Tsen et Lee). Protoplasma, 260 (1): 225-236. https://doi.org/10.1007/s00709-022-01771-0

FAO, 2023. Food and Agriculture Organization of the United Nations. (Web page: https://www.fao.org/faostat/en/#home) (Date accessed: July 2025)

Gupta, R. & S.K. Chakrabarty, 2013. Gibberellic acid in plant: still a mystery unresolved. Plant signaling & Behavior, 8 (9): e25504. https://doi.org/10.4161/psb.25504

Hedden, P. & S. G. Thomas, 2016. Annual Plant Reviews, The Gibberellins. John Wiley & Sons USA, 471 pp.

IPCC, 2021. Climate Change 2021. The Physical Science Basis. (Web page: https://www.ipcc.ch/report/ar6/wg1/) (Date accessed: March 2025)

Iwaniuk, P., S. Łuniewski, P. Kaczyński & B. Łozowicka, 2023. The Influence of humic acids and nitrophenols on metabolic compounds and pesticide behavior in wheat under biotic stress. Agronomy, 13 (5): 1378. https://doi.org/10.3390/agronomy13051378

Karaman, R., İ. Akgün & C. Türkay, 2021. "Effect of different harvest periods and nitrogen doses on the yield and quality properties in sweet corn, 903-914". III. Balkan Agriculture Congress (29 August-1 September), Trakya University Publisher, 993 pp.

Kılınç, S., Ş. Atakul, Ş. Kahraman, H. Aktaş, İ. Erdemci & İ. Gül, 2023. Ekim zamanlarının şeker mısır (*Zea mays saccharata* Sturt.) çeşitlerinde bazı verim ve kalite özelliklerine etkisi. Kahramanmaraş Sütçü İmam Üniversitesi Tarım ve Doğa Dergisi, 26 (2): 282-292. https://doi.org/10.18016/ksutarimdoga.vi.1049530

Kumar, A., R.D.S. Yadav & J.P. Gupta, 2020. Optimization of GA_3, DAP and boric acid for maximizing seed yield and its quality parameters in hybrid rice. International Journal of Chemical Studies, 8 (6): 184-191. https://doi.org/10.22271/chemi.2020.v8.i6b.10748

Kumlay, A. M. & T. Eryiğit, 2011. Substances that regulate growth and development in plants: plant hormones. Journal of the Institute of Science and Technology, 1 (2): 47-56.

Laksono, R.A., N.W. Saputro & Syafi'i, M. 2018. Respon pertumbuhan dan hasil beberapa varietas jagung manis *(Zea mays saccharata* Sturt. L) akibat takaran bokashi pada sistem Pengelolaan Tanaman Terpadu (PTT) di kabupaten Karawang. Kultivasi, 17 (1): 608-616.

Michalski, T., M. Bartos-Sychała, T. Maciejewski & A. Jarosz, 2008. “Effect of Biostymulator Asahi SL on Cropping of Maize Grown For Grain, 66-76”. In: Monographs Series: Biostimulators in Modern Agriculture: Field Crops (Eds. Z. T. Dąbrowski), The Editorial House Wieś Jutra, Warsaw, Poland, 377 pp.

Mishra, G.C., K. Avinash, S.K. Duvvada, B. Supriya, G. Mishra & A. Satapathy, 2020. Response of hybrid sweet corn (*Zea mays saccaharata*) to fertility levels with and without gibberellin on production potential and economics in Southern Odisha. Journal of Pharmacognosy and Phytochemistry, 9 (4): 242-245.

Mubarok, S., F.Y. Wicaksono, A. Nuraini, B.P.N. Rahmat & R. Budiarto, 2022. Agronomical characteristics of sweet corn under different plant growth regulators during the dry season. Biodiversitas Journal of Biological Diversity, 23 (6): 3091-3098. https://doi.org/10.13057/biodiv/d230636

Okumura, R.S., D. de Cinque Mariano, A.A.N. Franco, P.V.C. Zaccheo & T.O. Zorzenoni, 2013. Sweet corn: Genetic aspects, agronomic and nutritional traits. Applied Research & Agrotechnology, 6 (1): 105-114.

Othman, S. O., M. M. Mansour, S. H. Ali, & A. E. A Elboghdady, 2024. Stimulatory Effect of Some Artificial Regulators on the Growth Rate and Chemical Contents of Jackfruit Seedlings Grown in South Egypt. The Future of Horticulture, 4: 42-51. https://doi.org/10.37229/fsa.fjh.2024.11.05

Öktem, A. & A.G. Öktem, 2006. Determination of yield characteristics of some sweet corn (*Zea mays saccharata* Sturt) genotypes under Harran Plain conditions. Uludağ University Journal of Agriculture Faculty, 20 (1): 33-46.

Öktem, A. & A.G. Öktem, 2018. Effects of drought stress on sweet corn yield in semi-arid regions of Turkey. Turkish Journal of Agriculture and Forestry, 42 (3): 189-197.

Özata, E., 2019. Evaluation of fresh ear yield and quality performance in super sweet corn. International Journal of Life Sciences and Biotechnology, 2 (2): 80-94. https://doi.org/10.38001/ijlsb.566890

Rademacher, W., 2015. Plant growth regulators: backgrounds and uses in plant production. Journal of Plant Growth Regulation, 34: 845-872. https://doi.org/10.1007/s00344-015-9541-6

Revilla, P., C. M. Anibas & W. F. Tracy, 2021. Sweet corn research around the world 2015-2020. Agronomy, 11 (3): 534.

Shahniza, S.S., I.M. Firdaus & I. Roslan, 2020. Effect of time of application and concentrations of plant growth regulators on growth and yield of sweet corn (*Zea mays* L.). Research on Crops, 21 (1): 46-53. https://doi.org/10.31830/2348-7542.2020.007

Sopacua, B.N.H., A. Nuraini & M. Kadapi, 2022. Yield characteristics of sweet corn at different concentrations of gibberellic acid at high and medium land altitudes. Nongye Jixie Xuebao/Transactions of the Chinese Society of Agricultural Machinery, 53 (12): 1-12.

Srivastava, L.M., 2002. Plant Growth and Development: Hormones and Environment. Academic Press California, 846 pp.

Szparaga, A., S. Kocira, A. Kocira, E. Czerwińska, M. Świeca, E. Lorencowicz, R. Kornas, M. Koszel & T. Oniszczuk, 2018. Modification of growth, yield, and the nutraceutical and antioxidative potential of soybean through the use of synthetic biostimulants. Frontiers in Plant Science, 9: 1401. https://doi.org/10.3389/fpls.2018.01401

Taiz, L. & E. Zeiger, 2010. Plant physiology. 5th edn. Sunderland, MA: Sinauer Associates, Inc., Publishers, 782 pp.

Temiz, A. & S. Gökmen, 2023. Atdişi mısırının F1 ve F2 generasyonlarında verim ve verim unsurlarının belirlenmesi. ISPEC Journal of Agricultural Sciences, 7 (3): 489-507. https://doi.org/10.5281/zenodo.8303797

Uçak, A.B., A. Öktem, C. Sezer, R. Cengiz & B. Inal, 2016. Determination of arid and temperature resistant sweet corn (*Zea mays saccharata* Sturt) lines. Intennational Journal of Environmental & Agriculture Research, 2 (7): 79-88.

Yao, N., L. Zhang, F. Tian, K. Wang, Q. Li, J. Lu, M. Lyu & S. Wang. 2023. Compound sodium nitrophenolate promotes denitrification by nitrifying bacteria by upregulating nitrate reductase. Applied Science, 13: 6134. https://doi.org/10.3390/app13106134

Zhang, Y., M. Song, X. Rui, S. Pu, Y. Li & C. Li, 2015. Supplemental dietary phytosterin protects against 4-nitrophenol-induced oxidative stress and apoptosis in rat testes. Toxicology Reports, 2: 664-676. https://doi.org/10.1016/j.toxrep.2015.04.007