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Study the Effect of Adding Chemical Fertilizer and Spraying with Growth Regulator (Atonik) on the Growth, Production and Quality of the Okra Plant (*Abelmoschum esculentus* L.)

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ABSTRACT

Okra (*Abelmoschus esculentus* L.) has antidiabetic, antioxidant, anti-inflammatory, and hypolipidemic effects. Its polysaccharides and flavonoids lower blood glucose, while antioxidants reduce oxidative stress. It aids digestion, protects the liver and stomach, and has antimicrobial properties against pathogens like *S. aureus* and *E. coli*. This study investigated the effects of chemical fertilizer and Atonik growth regulator on okra growth, yield, and quality during the 2023-2024 season. The study aimed to evaluate how different fertilizer levels and Atonik concentrations influence okra's agronomic and biochemical traits. The experiment was conducted in an open field at Samarra University, Iraq, using a randomized complete block design (RCBD) with two factors: chemical fertilizer (D: 0, 70, 140 g L^{-1}) and Atonik (T: 0, 5, 10 mg L^{-1}). Data on plant height, leaf count, yield, pod number, and nutrient content were analyzed using GenStat, with means compared via LSD at $p \leq 0.05$. Chemical fertilizer (D) significantly increased plant height (158.22 cm), leaf number (139.66), yield (11.328 g/plant), pod count (5.740), carbohydrates (0.264%), and phosphorus (P%). Atonik (T) enhanced fruit weight (3.154 g), nitrogen (N%, 1.093), and potassium (K%, 1.867). The interaction (T×D) showed D2T0 improved height, pod count, and N%; D2T1 boosted fruit weight and yield; D1T1 increased K%; and D2T2 elevated P%. Combining chemical fertilizer (140 g L^{-1}) and Atonik (5–10 mg L^{-1}) optimized okra growth, yield, and nutrient content, demonstrating their synergistic potential in enhancing okra production.
Keywords: Chemical fertilizer, Atonik, Nutrient content, Okra, Yield quality

INTRODUCTION

Abelmoschus esculentus L. (Okra) exhibits several medicinal properties, including antidiabetic, antioxidant, anti-inflammatory, and hypolipidemic effects. The polysaccharides and flavonoids in okra pods have been shown to reduce blood glucose levels by inhibiting intestinal glucose absorption and enhancing insulin sensitivity [1]. Its high antioxidant content, particularly quercetin derivatives, helps mitigate oxidative stress and inflammation, potentially protecting against chronic diseases like cardiovascular disorders [2]. Okra also demonstrates gastroprotective and hepatoprotective effects due to its mucilage and fiber content, which aid digestion and reduce gastric irritation [3]. Additionally, okra seeds contain bioactive compounds with antimicrobial activity against pathogens like *Staphylococcus aureus* and *Escherichia coli* [4].

Okra (*Abelmoschus esculentus* L.) is recognized for its rich content of bioactive compounds, including polyphenols, flavonoids, carotene, vitamins (such as C, thiamine, riboflavin, niacin, and folic acid), and polysaccharides, which are distributed across its pods, seeds, leaves, and mucilage. These compounds contribute to a wide spectrum of medicinal properties, such as antioxidant, antidiabetic, cardioprotective, neuroprotective, anticancer, antiulcer, antibacterial, and anti-fatigue effects. For example, phenolic compounds and flavonoids in okra have demonstrated strong free radical scavenging activity, while specific flavonoids like isoquercitrin and hyperin have shown anticancer potential by inducing apoptosis in cancer cells. Okra polysaccharides, particularly those in the mucilage, exhibit hypoglycemic, immunomodulatory, and liver detoxification activities, and can bind cholesterol and bile acids, supporting cardiovascular and digestive health. Additionally, okra seeds are rich in oligomeric catechins and essential fatty acids (oleic and linoleic acids), which further enhance their antioxidant and cardioprotective benefits. Collectively, these bioactive constituents make okra a valuable functional food with potential applications in the management and prevention of chronic diseases such as diabetes, cancer, and cardiovascular disorders [5, 6].

The okra plant (*Abelmoschum esculentus* L.) One of the most important plants of the marsh family Malvaceae is desirable in a number of countries of the world, such as Africa, Asia, and Latin America [7]. It is one of the summer crops that are grown for their green fruits in different areas of Iraq. It is also a rich source of some vitamins (B1, B2, B3, C and K) as well as proteins, nutrients, carbohydrates and unsaturated oils [8]. As for the production of Okra crop in Iraq, it was estimated at 24.7 tons for 2015, compared to last year's production. The province of Babylon ranked first, followed by the province of Baghdad, as the quantities of production were estimated at 60.0 and 5.4 thousand tons each, with ratios of 24.4% and 21.9% of the total local production, respectively, according to the Central Statistical Organization (CSO) and the Directorate of Agricultural Statistics/ Iraq (2015). There are many studies conducted to improve the growth and production of the crop through many means, the most important of which is to secure the plant's need for nutrients, especially nitrogen, which is important in increasing the growth and yield of the plant [9].

The application of nitrogen at different concentrations (75, 100, and 125 kg ha^{-1}) on okra plants revealed that the highest concentration (125 kg N ha^{1}) produced the best growth and yield outcomes [10, 11]. Specifically, this treatment resulted in the tallest plants (92.4 cm $plant^{1}$), the highest number of leaves (23.4 leaves $plant^{-1}$), the greatest yield per plant (346.5 g $plant^{-1}$), and the highest total yield (7.6 tons hectare^{-1}). Additionally, it led to the maximum number of pods per plant (36.7 pods per plant^{1}) and the heaviest pod weight (9.8 g per pod^{1}), outperforming the other nitrogen treatments [12].

As for the use of plant growth regulators, they are important factors for increasing the growth and production of a number of agricultural crops, including cytokines, which have the main work in stimulating cell division and the growth of lateral shoots, and reducing apical sovereignty, which causes an increase in the number of vegetative and floral lateral branches, and then increasing production [13, 14]. Growth regulators are also one of the most efficient modern technologies used in the recent Aoni that improve plant growth processes by means that protect the environment from pollution on the one hand and improve productivity on the other hand and have become a common application in sustainable agriculture, because they lead to a reduction in the use of fertilizers and other chemical compounds in agricultural production [15]. Atonik is one of the most important growth organizations that has proven its high efficiency in improving the growth and yield of various horticultural plants [16].

His study was conducted to investigate the following aspects of the economically significant okra plant, which offers numerous benefits and is highly valued by consumers: the effect of chemical fertilizers on the growth and yield of Okra; the response of the okra plant to spraying with the Atonik growth regulator and its influence on growth and yield; and the interplay between these factors and their combined impact on the growth and yield of the Okra plant.

MATERIAL AND METHODS

The experiment was conducted in the open field of the research station at the Faculty of Agriculture, Samarra University in Balad, during the 2023-2024 growth season. The objective was to study the effects of adding chemical fertilizer and applying the growth regulator Atonik on the growth, yield, and quality of okra plants sourced from the Ministry of Agriculture. The research was designed as a randomized complete block design (RCBD) experiment. The study included two factors. The first factor, denoted as (D), involved the addition of chemical fertilizer to the soil in three levels: 0 g.L^-1 (D0), 70 g.L^-1 (D1), and 140 g.L^-1 (D2). The second factor, represented as (T), consisted of spraying the plants with Atonik at three concentrations: 0% (T0), 5% (T1), and 10% (T2). This resulted in a total of 9 treatment combinations across three replications, amounting to 27 trial units (333). oil samples were collected and sent to the Soil and Water Sciences Laboratory for analysis of their physical and chemical properties, with the results presented in Table 1.

The land was divided into plots, each measuring 75 cm in width and spaced 1 meter apart. Okra seeds were planted on March 15, 2023, in holes along the rows, with a distance of 40 cm between each hole. Four seeds were placed in each hole, which were located on one side of the plot. The experimental unit consisted of three sections, measuring 3.2 meters in length and covering an area of 5.6 m². An experiment was conducted with a factorial design (332), resulting in 18 experimental units. The first factor was the chemical fertilizer, represented by three levels: 0, 70, and 140 g L^{1}. The second factor was the growth regulator (Atonik), which had three concentrations: 0, 5, and 10 mg L^{-1}. The vegetative phase was sprayed twice: the first application occurred at the start of flowering on April 15, 2023, and the second was 20 days later. A diffuser, Tween 20, was added at a rate of 0.1% by volume to reduce the surface tension of the water and ensure complete wetting. In the control treatment, the plants were sprayed with water only, using a 5-liter hand sprayer in the early morning. Harvesting began on May 10, 2023, and continued until September 15, 2023.

Table 1 Physical and Chemical Properties of Field Soil

Title	Value
Sand	66.7
Reene	25.8
Ooze	7.5
Tissue	Clay mixtures
PH	7.64
Nitrate	11.2
Ammonium (mg.	16.5
P (g / kg $^{-1}$)	14.4
K (g / kg $^{-1}$)	3.9
E.C (ds. $^{m-1}$)	3.30
O.M (g /$^{kg-1}$)	10
Lime (g / kg $^{-1}$)	140
Gypsum (g / kg $^{-1}$)	8

RESULTS

The ANOVA results indicate significant effects of blocks, chemical fertilizer (D), Atonik (T), and their interaction (D × T) on the response variable. Both chemical fertilizer ($F = 60.5$, $p < 0.01$) and Atonik ($F = 38.9$, $p < 0.01$) had highly significant effects, as did their interaction ($F = 13.0$, $p < 0.01$). Blocks also showed a significant influence ($F = 3.2$, $p < 0.05$). The error term (MS = 23.1) accounted for unexplained variation. Overall, the model explained a substantial portion of the total variation (SS Total = 6320) (Table 2).

Table 2 The anova of the effect of Chemical Fertilizer and Atonik on some traits

Variation	df	SS	MS	F-value	Significance
Blocks (Replications)	2	150	75	3.2	*
Chemical Fertilizer (D)	2	2800	1400	60.5	**
Atonik (T)	2	1800	900	38.9	**
D × T Interaction	4	1200	300	13.0	**
Error	16	370	23.1	-	-
Total	26	6320	-	-	-

SS: Sum of Squares, MS: Mean Square, *, ** significant at 5 and 1 level, respectively.

The results presented in Table 3 show that the application of chemical fertilizer (D) at a level of 140 g is the most effective, yielding a height of 158.22 cm, compared to the control treatment, which measured 131.15 cm. In terms of the impact of the atonic regulator (T), it surpassed the control treatment at a concentration of 0 ml L-1, achieving an average height of 148.14 cm. Additionally, the interaction between chemical fertilizer and growth regulator (D*T) revealed that the treatment D2T0 was the most effective, recording a height of 207.34 cm, while the lowest height of 116.77 cm was observed in the other treatment.

Table 3 Effect of foliar spraying in the atonic and the effect of adding chemical fertilizer and their interference in the height of the okra plant (plant cm $^{-1}$)

Chemical Fertilizer (DAP) D	T-Atonic Acid			D
	T_0	T_1	T_2	
D_0	116.77	127.43	149.25	131.15
D_1	120.31	150.65	136.38	135.78
D_2	207.34	125.55	141.76	158.22
T-Atonic Acid Mean	148.14	134.54	142.46	
LSD $_{0.05}$	D=3.86	T=3.86	D*T =6.69	

The results in Table 4 show that the chemical fertilizer treatment D2 (140 g) performed significantly better, yielding 139,661 leaves—nearly double the control treatment's output of 77,333 leaves. Similarly, Atonic T was most effective at a 10 mL concentration, producing 133,223 leaves, compared to the control's 100,067 leaves. The interaction between chemical fertilizer and Atonic T (D × T) further enhanced results: the D2 × T1 combination achieved the highest leaf count (174,555 leaves), while D0 × T1 yielded the lowest (51,557 leaves).

Table 4 Effect of foliar spraying on the tonic and the effect of adding chemical fertilizer and their overlap Characteristic of the number of leaves is okra (leaf $^{-1}$)

Chemical Fertilizer (DAP) D	T-Atonic Acid			Mean Chemical Fertilizer (D)
	T_0	T_1	T_2	
D0	94.1100	51.5570	86.3323	77.3331
D1	120.7757	100.2250	154.2260	125.0765
D2	85.316	174.5550	159.1123	139.6633
T-Atonic Acid Mean	100.0674	108.7790	133.2236	
LSD 0.05	D = 0.007	T= 0.007	D*T =0.01288	

The results presented in Table No. 5 demonstrate the effectiveness of the growth regulator Atonik when sprayed at a concentration of 10 ml per liter, yielding the highest nitrogen percentage of 1.064%. In contrast, the lower concentration of 5 ml per liter resulted in the lowest percentage of 0.952%. Additionally, the application of chemical fertilizer at a concentration of 140 g per liter (D2) showed significant improvement, achieving a nitrogen percentage of 1.0934%, compared to the control treatment, which had a lower percentage of 1.026%. Furthermore, the interaction between the chemical fertilizer and the growth regulator (D*T) revealed that the treatment D2T0 significantly exceeded the others, resulting in the highest nitrogen percentage of 1.177% in the leaves.

Table 5 The Effect of Palatonic Spraying and the Effect of Adding Chemical Fertilizer and Their Interference in the Percentage of Nitrogen in the Okra Plant

Chemical Fertilizer (DAP) D	T-Atonic Acid			Mean Chemical Fertilizer (D)
	T_0	T_1	T_2	
D0	0.951	1.008	1.065	1.008
D1	0.950	1.065	0.841	0.952
D2	1.177	1.121	0.895	1.064
T-Atonic Acid Mean	1.026	1.065	1.0934	
LSD 0.05	D =0.1922	T= 0.1922	D. T.0.3328	

Table 6 shows the effect of adding chemical fertilizer. The treatment with a concentration of 140 g per plant (D2) resulted in the highest phosphorus percentage at 0.264%, while the lowest concentration of 70 g produced a percentage of only 0.14%. Regarding the effect of the growth regulator, spraying at a concentration of 10 ml per liter yielded the highest phosphorus percentage of 0.240%, compared to the lower concentration of 5 ml per liter, which resulted in 0.18%. Additionally, the combination of chemical fertilizer and growth regulator (D*T) showed that the treatment D2T2 was the most effective, achieving a phosphorus percentage of 0.466%, surpassing all other treatments.

Table 6 Effect of foliar spraying on atonic and the effect of adding chemical fertilizer and their interference in the percentage of potassium in the okra plant

Chemical Fertilizer (DAP) D	T-Atonic Acid			Mean Chemical Fertilizer (D)
	T_0	T_1	T_2	
D0	0.336	0.138	0.205	0.226
D1	0.237	0.153	0.048	0.146
D2	0.051	0.276	0.466	0.264
T-Atonic Acid Mean	0.204	0.189	0.240	
LSD 0.05	D =0.0580	T= 0.0580	D. T.0.1005	

The results of Table No. 7 indicate that the treatment of the addition with chemical fertilizer at a concentration of 70 g L^{-1} is morally superior, giving the highest rate of 1.785% compared to the comparison treatment, which gave the lowest rate of 1.672% in the percentage of potassium in the leaves of the okra plant. As for the effect of spraying with the Atonic growth regulator, the treatment of spraying with a concentration of 10 ml liters^{-1} was superior, giving the highest rate of 1.867% compared to the comparison treatment, which gave the lowest rate of 1.601%. With regard to the bilateral overlap between chemical fertilizer and growth regulator D*T, the treatment of spraying D1T1, which gave the highest rate of 1.928% compared to the rest of the treatments in the description of the percentage of potassium.

Table 7 Effect of foliar spraying in atonic and the effect of adding chemical fertilizer and their overlap in the percentage of potassium in the okra plant

Chemical Fertilizer (DAP) D	T-Atonic Acid			Mean Chemical Fertilizer (D)
	T_0	T_1	T_2	
D0	1.90800	1.35300	1.75500	1.67200
D1	1.70300	1.92800	1.72600	1.78567
D2	1.19300	1.89500	1.12200	1.77366
T-Atonic Acid Mean	1.60133	1.72533	1.86767	
LSD 0.05	D =0.0009	t.	D*T =0.001731	

The results presented in Table No. 8 show that adding chemical fertilizer (D) at a concentration of 140 g L^-1 resulted in the highest yield of 5,740 plant horns^-1. This is significantly higher than the comparison treatment, which yielded the lowest at 4.269 plant horns^-1. In contrast, the effect of spraying with the atonic regulator at a concentration of 10 ml L^-1 produced a yield of 4.363 plant horns^-1, which was the highest among the treatments T0 and T1, both of which recorded the same rate. Furthermore, the combination of chemical fertilizer and the atonic regulator (D*T) showed that the treatment D2T0 performed the best, achieving a moral superiority with a yield of 6,367plant horns^-1, surpassing all other treatments.

Table 8 Effect of foliar spraying on the atonic and the effect of adding chemical fertilizer and their overlap on the number of okra horns (plant horn $^{-1}$)

Chemical Fertilizer (DAP) D	T-Atonic Acid			Mean Chemical Fertilizer (D)
	T_0	T_1	T_2	
D0	2.328	4.925	0.553	4.269
D1	4.182	3.647	5.235	4.355
D2	6.367	4.516	6.337	5.740
T-Atonic Acid Mean	4.292	4.363	5.292	
LSD 0.05	D=0.39	T=0.39	D*T = 0.67	

The results of Table No. 9 indicate that the chemical fertilizer (D) at the level of 0 g L^{-1} gave the highest moral superiority of 3.011 g, while the concentration of 70 g was less than 3.008 g plant^{-1}. As for the effect of the Atonic regulator, the concentration gave 10 ml liters^{-1} moral superiority, which gave the highest rate of 3.154 g compared to the comparison treatment T_0, which gave the lowest rate of 2.068 g plant^{-1} in the terms of the weight of the fruit. As for the impact of the overlap between the chemical fertilizer and the atonic regulator, the treatment of spraying D2T1, which recorded the highest rate of 3.894 g plant^{-1} compared to the rest of the treatments, was superior.

Table 9 Effect of foliar spraying on the atonic and the effect of adding chemical fertilizer and their overlap in the weight of the fruit (g plant^{-1})

Chemical Fertilizer (DAP) D	T-Atonic Acid			Mean Chemical Fertilizer (D)
	T_0	T_1	T_2	
D0	1.82300	2.20533	2.90667	2.3116
D1	2.42433	3.25267	3.34900	3.0086
D2	1.95867	3.89400	3.20667	3.01978
T-Atonic Acid Mean	2.06867	3.11733	3.15411	
LSD 0.05	D=0.0025	T=0.0025	D*T = 0.004364	

Table 10 presents the effects of adding chemical fertilizer (D) on the percentage of carbohydrates in the okra plant. The results show that the highest carbohydrate content of 0.578% occurred with the application of D2 at a concentration of 140 g L-1. In contrast, the control treatment D0, with a concentration of 0 g L-1, resulted in the lowest carbohydrate percentage of 0.462%. Regarding the Atonic growth regulator, the T2 spraying treatment achieved the highest carbohydrate content at 0.453%, outperforming the control treatment, which recorded a lower rate of 0.335%. Additionally, the combination of chemical and Atonic fertilizers (D*T) revealed that the D2T0 spraying treatment was the most effective, resulting in a carbohydrate percentage of 0.607%, surpassing all other treatments.

Table 10 The effect of foliar spraying on the tonic and the effect of adding chemical fertilizer and their overlap in the percentage of carbohydrates in the okra plant.

Chemical Fertilizer (DAP) D	T-Atonic Acid			Mean Chemical Fertilizer (D)
	T_0	T_1	T_2	
D0	0.33500	0.52167	0.53110	0.46256
D1	0.41800	0.54700	0.56333	0.50944
D2	0.60733	0.57433	0.55333	0.57833
T-Atonic Acid Mean	0.45344	0.54767	0.54922	
LSD 0.05	D = 0.001	T= 0.001	D*T =0.01288	

The results of Table 11 indicate the effect of adding chemical fertilizer (D), where there was a moral superiority at the addition of a concentration of 140 g L^{-1} D_2, which gave the highest rate of 11.328 plant fruits $^{-1}$ compared to the treatment of D_0 at a concentration of 0 g L^{-1}, which gave the lowest rate of 5.497 plant fruits $^{-1}$ in the characteristic of the ratio of the output of one plant. As for the effect of the Atonic growth regulator, the treatment of spraying with a concentration of T_2 outperformed morally and gave the highest rate of. 10.429 plant fruit $^{-1}$ compared to the comparison treatment, which gave the lowest rate of 3.043 plant fruit $^{-1}$. Regarding the effect of the binary overlap between chemical fertilizer and atonic (D*T), the treatment of spraying D_2T_0, which amounted to 14.942 plant fruits $^{-1}$, was superior compared to the rest of the treatments.

Table 11 Effect of foliar spraying on the atonic and the effect of adding chemical fertilizer and overlapping them in the trait of one plant (plant fruit $^{-1}$) in the okra plant

Chemical Fertilizer (DAP) D	T-Atonic Acid			Mean Chemical Fertilizer (D)
	T_0	T_1	T_2	
D0	3.731	5.558	7.203	5.497
D1	4.997	6.977	11.442	7.805
D2	6.401	14.942	12.642	11.328
T-Atonic Acid Mean	3.043	9.159	10.429	
LSD 0.05	D =0.0765	T= 0.0765	D. T.0.1326	

DISCUSSION

This may be because many growth regulators enhance the plant's absorption of essential nutrients. This improvement promotes cell division and elongation, resulting in increased branching and leaf development. Consequently, the leaf area expands, positively impacting the crop and its components, ultimately leading to higher productivity per unit area. This is in line with what [17] found when spraying the atonic on the tomato plant, the concentration of 5% [18], and when spraying the atonic on the watermelon plant, and when spraying the atonic on the tomato plant, when spraying the regulator itself on the pumpkin plant is a variety Opaline [19].

The results of this study align with prior research demonstrating that diammonium phosphate (DAP) fertilizer significantly enhances plant growth. It has been reported [20] that increased crop height is associated with optimal fertilization. However, the finding that **atonic acid (T0) performed best (148.14 cm) contrasts with research that has been found [21] that higher concentrations of growth regulators typically improve plant height—suggesting that atonic acid may have inhibitory effects at elevated doses. The exceptional performance of D2T0 (207.34 cm) contributes new insights into fertilizer-regulator interactions, indicating that excessive growth regulators may negate fertilizer benefits, a phenomenon not widely documented. Practical implications include optimizing DAP application (140 g) while avoiding unnecessary atonic acid use, addressing a gap in growth regulator efficiency studies. Limitations include the focus on okra alone and the lack of soil health assessment, which may affect generalizability. Future research should explore alternative growth regulators [22], long-term soil impacts [23], and multi-environment trials to validate findings.

The current findings align with prior okra studies demonstrating fertilizer efficacy but reveal regulator-specific divergences. While the 140 g DAP treatment (139,661 leaves^{-1}) corroborates fertilizer benefits observed in GA3 trials, its superiority over lower doses contrasts with narcissus studies showing diminishing returns at high concentrations. The Atonic T1 treatment's optimal performance (174,555 leaves^{-1}) directly opposes Marsh *et al.*'s findings where growth regulators reduced leaf production [24], suggesting critical regulator-type specificity. These results address key gaps in growth regulator literature by demonstrating Atonic's unique stimulatory effect, though the narrow focus on leaf count (ignoring yield metrics [25] and soil impacts) limits agronomic applicability. Practical implications recommend D2T1 combinations for vegetative growth but caution against blanket regulator use given crop-specific responses. Future research should: 1) Validate results with yield measurements per farmer priorities [25], 2) Test Atonic against GA3/NAA combinations, and 3) Assess long-term soil nutrient balances under high-DAP regimes. This integrated approach could reconcile disciplinary gaps while addressing both physiological mechanisms and practical grower needs [25].

The findings of this study align with prior research demonstrating that growth regulators like Atonik and chemical fertilizers (e.g., DAP) enhance nutrient uptake in crops [26]. Similar to previous studies, our results confirm that higher concentrations of Atonik (10 mL L^{-1}) and DAP (140 g L^{-1}) significantly improve nitrogen (1.177%) and phosphorus (0.466%) levels in okra leaves, reinforcing established dose-response trends. This study provides novel insights by demonstrating the synergistic effects of combined treatments (D2T0 for nitrogen and D2T2 for phosphorus), a phenomenon that has been less documented in previous research. These findings address a significant research gap by optimizing integrated nutrient management strategies, offering practical implications for farmers to enhance okra productivity through targeted foliar and soil fertilization. However, a key limitation is that the study was conducted under controlled conditions, which may not accurately represent field variability in soil composition, climate, or pest pressures. Future research should examine these interactions in diverse agroecological settings, investigate the long-term impacts on soil health, and evaluate the economic feasibility for smallholder farmers [26].

The current findings align with prior research demonstrating that optimized concentrations of chemical fertilizers (e.g., DAP) and growth regulators (e.g., Atonik) enhance okra productivity. It has been reported [27, 28]. Improved potassium uptake (1.8–2.0%) with 70 g L^{-1} DAP, this study observed peak potassium levels (1.928%) under D1T1 (70 g L^{-1} DAP + 10 mL L^{-1} Atonik), highlighting a synergistic effect not previously quantified. Conversely, the superior fruit weight (3.894 g plant^{-1}) under D2T1 (140 g L^{-1} DAP + 5 mL L^{-1} Atonik) contrasts with previous research [27, 28], it have found higher yields with lower fertilizer doses, suggesting context-dependent efficacy. These results fill important gaps in precision agriculture by identifying optimal combinations of treatments for nutrient uptake (specifically potassium) and yield traits (such as horn number and fruit weight). However, key limitations include the lack of consideration for soil microbiome interactions and an analysis of economic feasibility, both of which could impact scalability. Future studies should examine these treatments in field conditions, assess cost-benefit ratios for farmers, and incorporate organic alternatives to minimize reliance on chemicals [27, 28].

The current findings demonstrate that higher concentrations of chemical fertilizer (140 g L-1 DAP) and Atonik growth regulator (T2) significantly improve carbohydrate content (0.578%) and fruit yield (14.942 fruits plant-1) in okra, aligning with previous research [28, 29] which has shown similar enhancements in carbohydrate accumulation with optimized fertilization. Our study reveals novel interactions, particularly highlighting the superior performance of the D2T0 treatment, which produced 0.607% carbohydrates and 14.942 fruits per plant. This contrasts with the findings of Singh et al. (2020), who reported better results with combined high-dose treatments. These results address critical gaps in precision nutrient management by identifying both optimal standalone and combinatorial treatments for enhancing okra productivity. However, key limitations include the controlled environment in which the study was conducted and the absence of an economic analysis, which may restrict its real-world applicability. Future research should explore these treatments under varied field conditions, assess their cost-effectiveness for farmers, and investigate the mechanisms underlying the unexpected superiority of the D2T0 treatment [28, 29].

CONCLUSION

In conclusion, applying 140g/L of chemical fertilizer (D2) and spraying with 10 ml/L of Atonic (T2) generally enhanced okra plant height, leaf number, and nutrient content. The D2T0 combination often yielded the highest results, except for potassium, where D1T1 excelled. These findings support optimized fertilizer and growth regulator use for improved okra yield.

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