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Integrated use of chicken manure and seaweed extract increased tomato yield at reduced nitrogen fertilization in semi-arid conditions

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Excessive use of synthetic fertilizers has caused serious environmental and health concerns. In this context, bio-stimulants such as seaweed extract and organic fertilizers like chicken manure can play a vital role in mitigating these impacts and improve crop performance. Two field experiments were conducted over two successive summer seasons to evaluate the effects of foliar seaweed extract (SWE) (0 mL/L, 2 mL/L, 4 mL/L) and chicken manure (ChM) (0 t/ha, 11. t/ha 9, 23.81 t/ha) in combination with 75% of the recommended nitrogen rate on growth, yield components, total yield, and fruit quality of tomato (*Solanum lycopersicum* L., cv. Red Jayda). Nine selected treatments, including a control, were tested to assess the interaction of SWE and ChM at reduced nitrogen. The results indicated that combining chicken manure and seaweed extract with a reduced nitrogen fertilizer rate (75% of the recommended level) significantly enhanced tomato growth, yield, and fruit quality. Foliar application of seaweed extract four times, in combination with 75% of the recommended mineral fertilizer dose and without chicken manure, significantly increased tomato yield. Total yield increased by 38.04% and 36.13% at an application rate of 2 mL/L during the first and second seasons, respectively. Increasing the concentration to 4 mL/L further enhanced yield by 49.81% and 48.26% per hectare in the first and second seasons, respectively, compared with the treatment receiving the same fertilizer rate without seaweed extract. These results indicate that the use of seaweed extract can reduce mineral nitrogen fertilizer input by up to 25% while maintaining or improving tomato productivity. Fruit quality also improved significantly, as reflected by higher nitrogen, phosphorus, potassium, and protein contents. Overall, these findings demonstrate that integrating organic fertilization and seaweed extract bio-stimulants offers a sustainable strategy to enhance tomato

productivity, improve fruit quality, and reduce reliance on chemical fertilizers in semi-arid regions.

KEYWORDS

bio-stimulant, chicken manure, fruit quality, seaweed extract, tomato (*Solanum lycopersicum* L), yield

1 Introduction

Tomato (*Solanum lycopersicum* L) is considered one of the world's most important vegetable crops and is also one of Egypt's more popular vegetables. In Egypt, tomato ranks among the leading vegetable crops, for both local consumption and export markets (Ouda et al., 2020). Tomato is vastly used both as salads and for cooking. Besides that, it has high nutritional values as it is the rich source of nutrients K, Fe, Na, vitamin A, vitamin C and antioxidants especially lycopene and salicylate (Pereira et al., 2022). The area cultivated with tomatoes in Egypt reached about 173,741.4 ha. during 2020 season according (FAOStat, 2021), which produced 7,229,108 tons with average of 41.607 tons/ha.

However, tomato production in semi-arid regions such as Egypt faces several challenges, including poor soil fertility, low organic matter, and high evapotranspiration rates. These factors often lead farmers to rely heavily on synthetic nitrogen fertilizers to achieve satisfactory yields. Although nitrogen is essential for tomato growth and fruit development, its excessive use has resulted in serious environmental and agronomic problems, including nitrate leaching, soil degradation, and reduced microbial diversity (Odegard and Van der Voet, 2014; Suchithra et al., 2022; Agaba et al., 2023). Furthermore, the rising costs of mineral fertilizers have increased production expenses and threatened the sustainability of smallholder farming systems. Consequently, developing sustainable fertilization strategies that maintain yield while reducing nitrogen dependency has become a major research priority.

Organic amendments, such as chicken manure, represent an environmentally friendly alternative that improves soil structure, water-holding capacity, and microbial activity (Scotti et al., 2016; Reddy et al., 2017). These materials provide a gradual release of nutrients and enhance soil biological health, thereby contributing to long-term soil fertility improvement. Nevertheless, organic fertilizers alone may not fully meet crop nutrient demands during critical growth stages. Thus, integrating them with complementary bio-stimulants could enhance nutrient uptake and plant productivity (Singh et al., 2022).

Foliar fertilization is an effective strategy to alleviate nutrient deficiencies and minimize problems associated with excessive use of mineral fertilizers. It enables rapid nutrient uptake through leaf tissues, particularly under conditions that restrict root absorption, such as alkaline soils in semi-arid regions (Alotaibi et al., 2024). This technique enhances nutrient balance, improves plant growth and yield, and serves as an efficient means of applying bio-stimulants like *Ascophyllum nodosum* seaweed extract.

Seaweed extracts, particularly those derived from *Ascophyllum nodosum*, have received increasing attention as natural plant

bio-stimulants capable of enhancing plant growth, nutrient use efficiency, and tolerance to abiotic stress (Van Oosten et al., 2017; Khan et al., 2009; Di Stasio et al., 2018; Nour et al., 2010; Ahmed et al., 2022). *Ascophyllum nodosum* extract contains bioactive compounds such as cytokinins, auxins, betaines, amino acids, and polysaccharides that stimulate root development, increase chlorophyll content, and improve nutrient uptake. Moreover, these extracts are biodegradable, non-toxic, and compatible with sustainable agricultural practices. Seaweed extracts are natural bioactive substances rich in microelements such as boron (B), molybdenum (Mo), zinc (Zn), and copper (Cu), as well as vitamins, minerals, carbohydrates, proteins, and fats. In addition, seaweed-based fertilizers contain a unique combination of trace elements, phosphorus, potassium, and simple sugars in dissolved forms that are readily absorbed through both roots and leaves. They also promote the release of soil-bound trace elements, making them safe for humans, animals, and the environment (Mannino et al., 2020). Therefore, seaweed extracts are considered promising and eco-friendly bio-stimulants that can enhance crop productivity, improve nutrient utilization, and mitigate environmental stress. Their integration into crop management practices represents a sustainable approach to reducing the reliance on synthetic fertilizers and promoting environmentally responsible agriculture. Understanding the relationships among growth, yield, and fruit quality traits is essential for optimizing nutrient management strategies in tomato production systems. Correlation analysis has been widely used to elucidate the interdependence among agronomic and physiological traits, providing insights into the key factors driving crop productivity (Khan et al., 2009; Rouphael et al., 2017). Such approaches are particularly important under integrated fertilization systems, where multiple inputs simultaneously influence plant performance.

Recent studies have demonstrated the beneficial effects of *Ascophyllum nodosum* extract on the vegetative growth, yield, and fruit quality of tomatoes. However, little attention has been given to its potential role in reducing nitrogen fertilizer inputs in semi-arid environments, especially when combined with organic amendments like chicken manure. Understanding these interactions could provide practical insights for optimizing fertilization programs, improving soil health, and minimizing environmental impacts. Despite these well-documented benefits, most previous studies have investigated seaweed extracts or organic fertilization separately, with limited attention to their combined application under reduced nitrogen inputs, particularly in semi-arid environments (Khan et al., 2009; Bulgari et al., 2015; Rouphael et al., 2017; Bulgari et al., 2019).

Sustainability in agricultural production is a key factor for ensuring food security while minimizing negative environmental

TABLE 1 Monthly mean climatic parameters during the growth and development of tomato plants at the experimental site during the 2022/2023 and 2023/2024 seasons.

Month	Year	TMIN (°C)	TMAX (°C)	TDEW (°C)	RH2M (%)	PRECTOTCORR (mm/day)	WS2M (m/s)
November	2022	14.52	26.85	10.50	59.70	0.03	2.18
November	2023	16.16	28.73	12.47	61.46	0.08	2.26
December	2022	12.10	24.21	9.37	64.97	0.82	2.06
December	2023	12.33	23.88	11.20	71.45	0.85	2.32
January	2023	9.07	21.46	8.08	70.42	1.38	2.12
January	2024	9.16	21.07	6.57	63.80	0.57	2.24
February	2023	7.52	20.03	6.36	68.68	0.54	2.29
February	2024	8.78	21.97	7.50	67.95	0.39	2.21
March	2023	11.54	26.75	6.86	54.40	0.26	2.68
March	2024	10.95	26.53	7.24	57.18	0.19	2.39
April	2023	13.91	30.89	7.36	46.90	0.19	2.84
April	2024	15.10	32.66	9.51	51.57	0.07	2.93

TMIN, monthly mean minimum temperature at 2 m; TMAX, monthly mean maximum air temperature at 2 m; TDEW, dew/frost point at 2 m; RH2M, relative humidity at 2 m; WS2M, wind speed at 2 m; PRECTOTCORR, precipitation rate (mm/day).

impacts. In tomato production, sustainable strategies such as the use of organic fertilizers and seaweed extracts play an important role in improving crop quality and enhancing productivity while reducing reliance on intensive chemical fertilizers. Studies have shown that seaweed extracts contain a wide range of nutrients, plant hormones, and bioactive compounds that stimulate plant growth and enhance resistance to environmental stresses (Khan et al., 2009; Nour et al., 2010; Craigie, 2011; Yusuf et al., 2023). Similarly, poultry manure is a rich source of nitrogen, phosphorus, and potassium, and contributes to improving soil structure and increasing organic matter content, thereby enhancing natural soil fertility (Singh et al., 2020; Adesemoye et al., 2009). Combining the use of seaweed extracts with poultry manure enhances tomato productivity and fruit quality while reducing dependence on chemical fertilizers, supporting sustainable agricultural goals and conserving natural resources (Usanmaz and Atti, 2020).

Understanding the interaction between organic amendments and seaweed-based bio-stimulants could provide a practical and sustainable approach for optimizing nutrient management and improving crop performance under resource-limited conditions (Bulgari et al., 2015; Rouphael et al., 2017; Bulgari et al., 2019; Du Jardin, 2015). It was hypothesized that integrating *Ascophyllum nodosum* seaweed extract with organic and reduced mineral nitrogen fertilization would enhance tomato growth, yield, and fruit quality under semi-arid conditions, while minimizing the reliance on synthetic nitrogen fertilizers. Therefore, the objectives of this study were to evaluate the effects of integrating reduced mineral nitrogen (75% RDF) with different rates of chicken manure (0 t/ha, 11.9 t/ha, and 23.81 t/ha) and foliar application of *Ascophyllum nodosum* seaweed extract (0 mL/L, 2 mL/L, and 4 mL/L) on tomato growth, yield, and fruit quality under semi-arid conditions, and to identify the optimal fertilization strategy that maximizes productivity and fruit nutrient composition while reducing mineral nitrogen input by 25% without compromising yield.

2 Materials and methods

2.1 Site description

During the two successive seasons of 2022–2023 and 2023–2024, two field experiments were conducted at the Experimental Farm of the Faculty of Technology and Development, Zagazig University, Ghazala, Zagazig, El Sharkia Governorate, Egypt (30°34′11.0″N, 31°34′24.5″E). The experiments were designed to evaluate the effect of selected combinations of mineral nitrogen fertilization, chicken manure, and foliar application of *Ascophyllum nodosum* seaweed extract on the growth, yield, and fruit quality of tomato (*Solanum lycopersicum* L.) cv. Red Jayda. Monthly climatic data during the growth and development of tomato plants at the experimental site in the 2022–2023 and 2023–2024 growing seasons were obtained from the Prediction of Worldwide Energy Resources (NASA POWER) database (Project, NASA POWER, 2024), which provides satellite-derived agro climatological parameters (Table 1).

2.2 Experimental design

The experiment consisted of nine selected treatments designed to evaluate the combined effects of mineral nitrogen fertilizer, chicken manure, and foliar application of seaweed extract on tomato plants. The analysis of the experimental soil field is presented in Table 2. Chemical analysis of chicken manure at the two seasons 2022–2023 and 2023–2024, is presented in Table 3. The treatments were not arranged as a full factorial design. Instead, three levels of chicken manure (0 t/ha, 11.9 t/ha, and 23.81 t/ha) and three concentrations of seaweed extract (0 mL/L, 2 mL/L, and 4 mL/L) were evaluated under a fixed reduced mineral nitrogen rate (75% RDF), with two additional reference treatments: an unfertilized control; T1 (0% RDF, no ChM, no SWE) and a conventional fertilization treatment; T2 (100% RDF without ChM or SWE). The nine treatments are listed as follows:

TABLE 2 The characteristics of the experimental soil.

Analysis	2022–2023	2023–2024
Coarse sand %	22.34	22.38
Fine sand %	9.78	9.75
Silt %	23.67	23.71
Clay %	44.21	44.16
Textural class	Clay	Clay
Organic matter (%)	1.80	1.80
Bulk density (g.cm ⁻³)	1.30	1.30
EC (dS.m ⁻¹) in soil paste extract	2.77	2.77
pH (in 1 soil:2.5 water suspension)	8.22	8.22
Plant nutrients–available (mg.kg⁻¹)		
N	27.18	27.18
P	16.23	16.23
K	170.12	170.12

EC, electric conductivity.

TABLE 3 Chemical properties of chicken manure used during the 2022–2023 and 2023–2024 seasons.

Chicken manure properties	2022–2023	2023–2024
Organic matter %	54.83	53.49
pH (1:10)	7.68	7.89
EC (dSm ⁻¹)	2.41	2.53
C/N ratio	15.78	15.86
Total N (%)	3.46	3.43
Total P (%)	0.83	0.81
Total K (%)	1.86	1.75
Total Ca (%)	1.94	1.89
Total Zn (ppm)	127	121
Total Cu (ppm)	178	167
Bulk density (g cm ⁻³)	0.55	0.55

T1: 0 RDF+0 ton/ha (ChM) +0 ml/L SWE (water spray only)

T2: 100%RDF+0 ton/ha (ChM) +0 ml/L SWE

T3: 75%RDF+0 ton/ha (ChM) +0 ml/L SWE

T4: 75%RDF+0 ton/ha (ChM) +2 ml/L SWE

T5: 75%RDF+0 ton/ha (ChM) +4 ml/L SWE

T6: 75%RDF+11.9 ton/ha (ChM) +2 ml/L SWE

T7: 75%RDF+11.9 ton/ha (ChM) +4 ml/L SWE

T8: 75%RDF+23.81 ton/ha (ChM) +2 ml/L SWE

T9: 75%RDF+23.81 ton/ha (ChM) +4 ml/L SWE

Seaweed extract was applied as a foliar spray four times at 30 days, 45 days, 60 days, and 75 days after transplanting (DAT). Control treatments received foliar sprays of water at the same application times to ensure consistency. A randomized complete block design (RCBD) with three replications was adopted. The seaweed extract (*Ascophyllum nodosum* L.) used in this study, the chemical composition of the seaweed extract is presented in Table 4.

TABLE 4 Major constituents of the seaweed extract (SWE) used in the experiment.

Items	Result
Water solubility %	100
Moisture %	5.0
pH value	7.2
Organic matter %	51
Alginic acid %	23
Total amino acid %	2.0
Potassium (as K ₂ O%)	18
Total nitrogen%	1.2
P ₂ O ₅ %	1.9
Betaine%	0.2
Cytokinin, ppm	80
Auxins, ppm	85
Gibberellin, ppm	60
Mannitol%	2.6
Polyphenols%	0.5
Absciscic acid (ABA)	20 ppm
Magnesium (Mg)	0.2%
Sodium (Na)	1%
Boron (B)	0.2%
Iron (Fe)	200 ppm
Zinc (Zn)	27 ppm
Copper (Cu)	7 ppm
Manganese (Mn)	2 ppm

The source of seeds of Red Jayda cultivar was Bayer German Company. Seeds were sown on fifth and seventh of November in 2022 and 2023 seasons and were transplanted on 11th and 12th of December in 2022 and 2023 seasons, respectively. Plot area was 9 m² which contained four ridges with 3m length and 0.75m wide, plants were transplanted at 30 cm apart.

The chicken manure, phosphate fertilizer P, one-third of potassium fertilizer, and one-third of nitrogen fertilizer were added while preparing the soil for planting, while the rest of the potassium and nitrogen fertilizer (the other two-thirds) were added in two equal doses after 45 days and 75 days after transplanting. Phosphorus fertilizer was added at a rate of 1,070 kg/ha of calcium super phosphate fertilizer (15.5% P₂O₅), and potassium fertilizer was added at a rate of 476 kg/ha of potassium sulfate (48% K₂O). The irrigation method used was the flow irrigation system. The physicochemical characteristics of the irrigation water used in the experiment are presented in Table 5.

The recommended dose of nitrogen fertilizer is 120 kg N/ha and was applied as ammonium sulfate (20.5% N). Nitrogen fertilizer was applied in split doses, where 50% of the assigned nitrogen rate (100%, 75% RDF) was incorporated into the soil before transplanting, and the remaining 50% was applied 1 month after transplanting. For the 0% RDF treatment, no mineral nitrogen was applied at either stage. All agricultural operations were carried

TABLE 5 The physicochemical characteristics of the irrigation water used in the experiment.

Analysis	2022–2023	2023–2024	Unit
Ca ⁺⁺	1.98	1.99	meq/L
Mg ⁺⁺	3.98	3.99	
K ⁺	0.16	0.17	
Na ⁺	2.20	2.21	
CO ₃ ⁻	0.00	0.00	
HCO ₃ ⁻	3.01	3.01	
Cl ⁻	5.09	5.10	
SO ₄ ⁻	0.39	0.40	
pH	7.1	7.2	dS/m
Ec	0.84	0.85	

out in accordance with the technical recommendations of the Egyptian Ministry of Agriculture in the commercial production of tomatoes, including service operations such as tilling, planning and preparing the soil for planting, irrigation, fertilization, pest control, and other practices.

2.3 Data recorded

A. Plant growth traits

A random sample of five plants from each subplot was taken 90 days after transplanting, and the next traits were determined: stem length, number of branches/plants, number of leaves/plants, fresh weight/plant, dry weight/ plant and plant samples were oven-dried at 60 °C to constant weight following the recommendations of Jones J. B. Jr. (1991) and AOAC (1995).

B. Yield and its components

Upon reaching full-ripe maturity, the fruits of each plot were harvested, then weighed and counted. Then we calculated the following data: yield/plant, average weight of fruit (g), number of fruits/plant, total yield/ha.

C. Fruit quality

A sample of 100 gm of fruits from each sub plot were taken at full-ripe maturity stage from the second harvest was oven dried at 60 °C till stable weight and the contents of phosphorus, nitrogen, and potassium were determined according to the methods described by AOAC (1995), in both growing seasons. Total protein percentage: total N in fruit was estimated, and a factor of 6.25 was used to convert total N to protein percentage (Kelly and Bliss, 1975).

2.4 Statistical analysis

Collected data were subjected to suitable statistical analysis of variance according to Snedecor and Cochran (1980) and the

differences among treatments were compared using Duncan's multiple range test (Duncan, 1958) of probability, the significance level ($p \leq 0.05$), with CoStat software (CoStat, 2005). In addition, Pearson's correlation coefficients were calculated for both seasons to evaluate the relationships among vegetative growth traits, yield components, and fruit quality parameters. The correlation matrix was visualized as a correlogram using R software (version 4.2.0; R Core Team, 2022) with the "corrplot" package (Wei and Simko, 2021).

3 Results

3.1 Plant growth traits

The data presented in Table 6 indicate that there were significant differences among all the treatments under study with respect to stem length, number of branches per plant, and number of leaves per plant in tomato. All studied treatments recorded higher values for these traits compared with the control treatment: no mineral fertilization + no chicken manure + no seaweed extract spray (T1: 0 RDF +0 tons/ha (ChM)+0 ml/L SWE), which showed the lowest values during both seasons of the study. The values varied according to the rates of nitrogen fertilization, organic fertilization levels, and the concentrations of seaweed extract spray. Foliar application of different concentrations of seaweed extract (SWE) significantly increased stem length (cm), number of branches per plant, and number of leaves per plant compared with the unsprayed plants (control) in both seasons (Table 6). The results also showed that stem length (cm), number of leaves per plant, and number of branches per plant increased gradually and significantly with foliar application of seaweed extract at concentrations of 2 mL/L and 4 mL/L, when applied with the same nitrogen fertilization rate and under the same levels of chicken manure fertilization, when these traits were evaluated 90 days after planting in both seasons. Furthermore, the results indicated that the same traits increased progressively and significantly with the application of poultry manure and with increasing rates of chicken manure, when assessed 90 days after planting during both growing seasons.

Stem length, number of branches per plant, and number of leaves per plant were significantly enhanced by the application of 75% RDF combined with ChM and SWE, with the highest values recorded under 75% RDF + 23.81 ton/ha ChM + 4 ml/L SWE in both growing seasons (Table 6).

Similarly, significant differences among treatments were observed for yield-related traits, including number of fruits per plant and fresh and dry biomass per plant (Figure 1). The combined application of 75% RDF with higher ChM and SWE rates consistently resulted in superior performance compared with the control, which recorded the lowest fresh and dry weights in both seasons. For the average fruit weight (g), yield per plant (kg), and total yield (tons/ha) of tomato plants, the data presented in Figure 2 showed that there were significant differences among all the treatments under this study. The treatments; 75%RDF+23.81 ton/ha (ChM)+4 ml/L SWE, and 75%RDF+23.81 ton/ha (ChM)+2 ml/L SWE, recorded the highest values of average fruit weight (g), yield per plant (kg), and total yield

TABLE 6 Effects of three levels of recommended dose of mineral fertilizer, three levels of chicken manure, and spraying with seaweed extract on stem length (SL) (cm), number of leaves per plant (NL), and number of branches per plant (NB) at 90 days after transplanting of tomato plants during the 2022–2023 and 2023–2024 seasons.

Treatments	SL		NL		NB	
	2022/2023	2023/2024	2022/2023	2023/2024	2022/2023	2023/2024
T1	51.67f	53.33f	21.66f	22.66e	1.43d	1.41d
T2	64.42d	64.13de	25.32e	25.32e	1.77d	1.73d
T3	61.24e	61.43e	22.70ef	22.70e	1.59d	1.55d
T4	63.00de	61.33e	30.66d	31.33d	2.27c	2.27c
T5	64.33d	65.00d	32.00d	32.66d	2.41c	2.40c
T6	76.33c	75.67c	35.66c	38.66c	2.50c	2.47c
T7	77.00c	78.33c	37.00c	39.66c	3.03b	2.90b
T8	90.00b	90.33b	51.66b	53.33b	4.04a	4.06a
T9	101.33a	102.67a	64.33a	62.66a	4.32a	4.37a

T1, 0 RDF+0 ton/ha (ChM)+0 ml/L SWE; T2, 100%RDF+0 ton/ha (ChM)+0 ml/L SWE; T3, 75%RDF+0 ton/ha (ChM)+0 ml/L SWE; T4, 75%RDF+0 ton/ha (ChM)+2 ml/L SWE; T5, 75%RDF+0 ton/ha (ChM)+4 ml/L SWE; T6, 75%RDF+11.9 ton/ha (ChM)+2 ml/L SWE; T7, 75%RDF+11.9 ton/ha (ChM)+4 ml/L SWE; T8, 75%RDF+23.81 ton/ha (ChM)+2 ml/L SWE, and T9, 75%RDF+23.81 ton/ha (ChM)+4 ml/L SWE. Different alphabetical letters after values indicate significant differences at 0.05 level of significance, according to Duncan's multiple range test.

(tons/ha), followed by 75%RDF+11.9 ton/ha (ChM)+4 ml/L SWE; 75%RDF+11.9 ton/ha (ChM)+2 ml/L SWE; 75%RDF+0 ton/ha (ChM) +4 ml/L SWE; and 75%RDF+0 ton/ha (ChM)+2 ml/L SWE; during the two studied seasons, respectively. The lowest value of average fruit weight (g), yield per plant (kg) and total yield (ton/ha) were recorded for the control treatment (0%RDF+0 ton/ha (ChM)+0 ml/L SWE), in both studied seasons, respectively, [Figure 2](#).

3.2 Fruit quality

The results showed significant differences in the chemical composition of tomato fruits, including nitrogen (N), phosphorus (P), potassium (K), and total protein content (%), due to the applied treatments ([Table 7](#)). Increasing N fertilization rates, organic fertilization (ChM), and seaweed extract (SWE) spraying significantly enhanced all measured parameters in both growing seasons.

The highest N, P, and total protein values were obtained with treatments combining 75% RDF with 23.81 ton/ha or 11.9 ton/ha ChM and 2 ml/L or 4 ml/L SWE, whereas the control (0% RDF + 0 ChM + 0 SWE) consistently recorded the lowest values. Similarly, the highest potassium content was achieved under 75% RDF combined with ChM and SWE at the same rates, while the control exhibited the lowest K content in both seasons ([Table 7](#)).

3.3 The correlation analysis

The correlation analysis revealed strong and positive relationships among most of the studied traits in both growing seasons ([Figure 3](#)). Vegetative growth parameters, including stem length, number of leaves, number of branches, fresh weight, and dry weight, were highly correlated with yield components such as number of fruits per plant, average fruit weight, and total yield. In

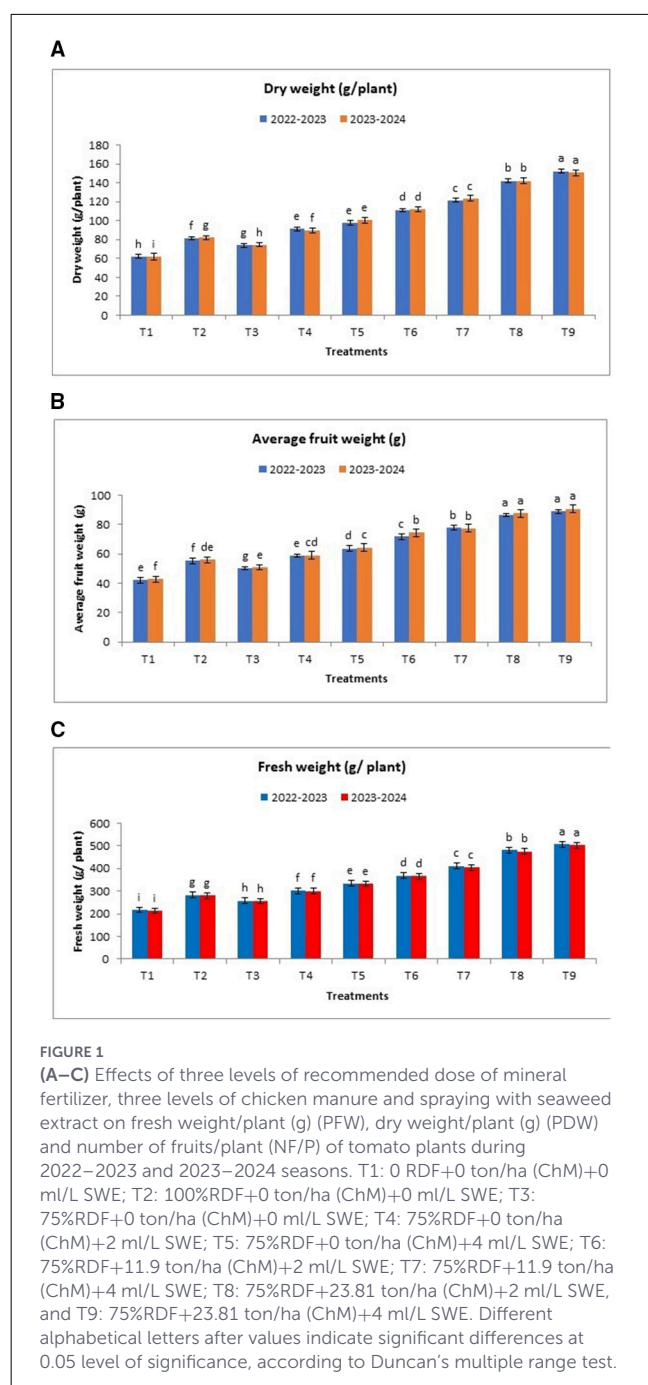
addition, fruit nutrient contents (N, P, and K) and total protein content exhibited strong positive correlations with total yield ($r = 0.88\text{--}0.96$), indicating that improved nutrient status was closely associated with enhanced productivity. The consistency of these relationships across both seasons highlights the stability of the observed responses under different environmental conditions.

4 Discussion

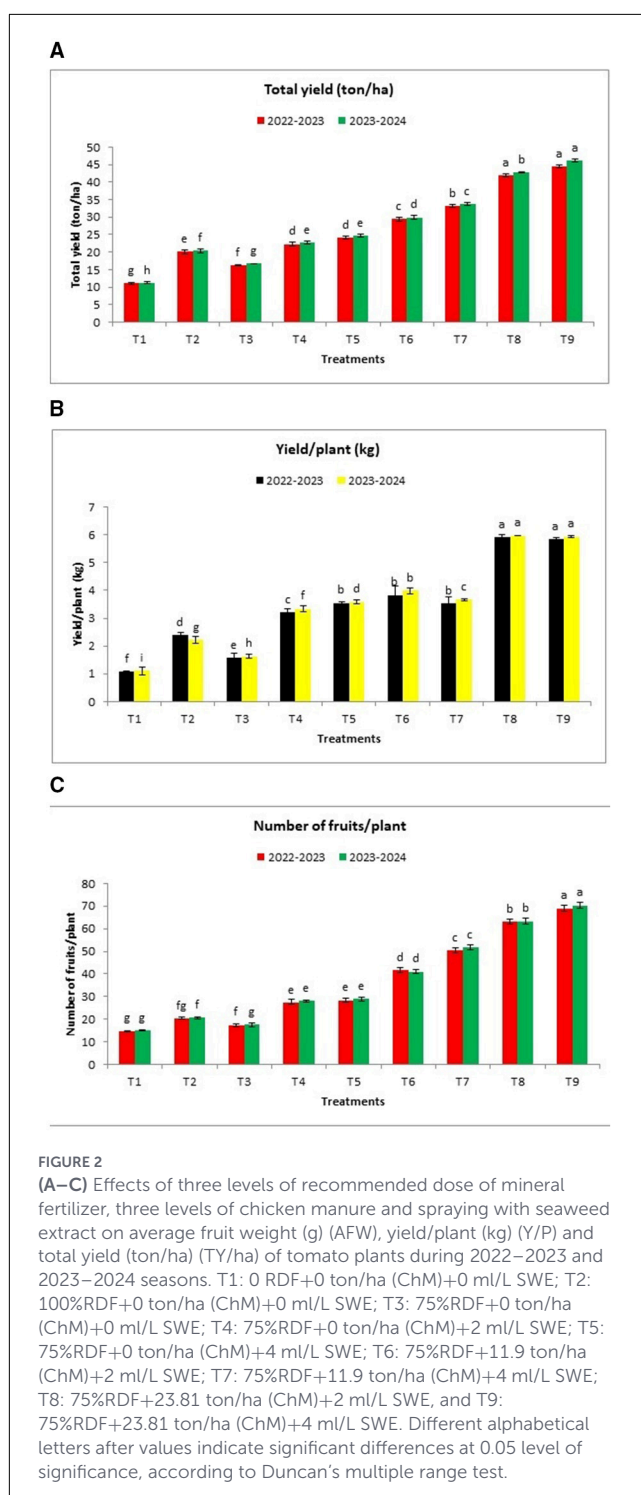
4.1 Plant growth traits and tomato fruit productivity in response to different fertilizer treatments

The results of the present study revealed statistically significant differences among the investigated treatments in several growth and productivity parameters of tomato plants, including stem length, number of branches per plant, number of leaves per plant, fresh and dry weight per plant, fruit weight, number of fruits per plant, yield per plant, total yield (tons/ha), as well as fruit nitrogen, phosphorus, potassium, and total protein contents. Increasing the rates of mineral and organic fertilization, combined with foliar application of seaweed extract, significantly improved all studied traits during both growing seasons ([Tables 6, 4](#); [Figures 1, 2](#)).

These results are consistent with the results obtained by [Tao et al. \(2022\)](#) and [Hernández-Herrera et al. \(2022\)](#), they found that, replacing chemical nitrogen fertilizers with organic sources represents an environmentally sustainable strategy that can enhance productivity while reducing environmental pollution through reduced use of chemical nitrogen fertilizers. Chicken manure contains considerable amounts of nitrogen in organic form, which is released more gradually than inorganic nitrogen supplied through mineral fertilizers. Therefore, combining organic fertilizers with inorganic nitrogen sources can provide a continuous supply of plant-available nitrogen, meeting plant requirements



throughout different growth stages, particularly during periods of rapid vegetative growth. In addition to nitrogen, organic fertilizers supply essential macronutrients such as phosphorus and potassium, along with important micronutrients including magnesium, calcium, sulfur, and manganese, which contribute to improved soil fertility and nutrient balance (Khaïtov et al., 2019). Furthermore, organic amendments stimulate microbial activity in the rhizosphere, leading to the production of plant growth regulators such as auxins and gibberellins that promote plant growth and development (Khaïtov et al., 2019; Tao et al., 2022). The findings of the present study showed that tomato fruit productivity increased progressively with increasing rates of



chicken manure while maintaining a constant nitrogen application rate. These results suggest that part of the chemical nitrogen fertilizer can be effectively replaced by organic fertilization without reducing crop productivity. Consequently, reducing dependence on inorganic nitrogen fertilizers may help mitigate environmental risks associated with intensive fertilization while maintaining high tomato yield.

TABLE 7 Effects of the nitrogen fertilizer, chicken manure and spraying with seaweed extract on nitrogen content (%) in fruits, phosphorus content (%) in fruits, potassium content (%) in fruits and total protein content (%) in fruits of tomato plants during 2022–2023 and 2023–2024 seasons.

Treatments	N/fruit%		P/fruit%		K/Fruit%		Protein %	
	2022/2023	2023/2024	2022/2023	2023/2024	2022/2023	2023/2024	2022/2023	2023/2024
T1	1.00 ^d	1.17 ^e	0.13 ^f	0.14 ^f	1.48 ^d	1.48 ^g	6.29 ^d	7.32 ^d
T2	1.32 ^c	1.54 ^d	0.18 ^{de}	0.18 ^{de}	1.94 ^c	1.95 ^{ef}	8.26 ^c	9.61 ^c
T3	1.20 ^{cd}	1.40 ^{de}	0.16 ^{ef}	0.16 ^e	1.77 ^{cd}	1.77 ^f	7.49 ^{cd}	8.73 ^{cd}
T4	1.70 ^b	1.85 ^c	0.20 ^{cd}	0.20 ^{cd}	2.37 ^b	2.40 ^{cd}	10.62 ^b	11.56 ^b
T5	1.63 ^b	1.83 ^c	0.21 ^{bc}	0.22 ^{bc}	2.45 ^b	2.22 ^{de}	10.18 ^b	11.45 ^b
T6	2.38 ^a	2.38 ^b	0.20 ^{bc}	0.21 ^c	2.46 ^b	2.54 ^c	14.88 ^a	14.88 ^a
T7	2.40 ^a	2.52 ^{ab}	0.24 ^{ab}	0.24 ^{ab}	3.19 ^a	3.02 ^b	15.00 ^a	15.72 ^a
T8	2.32 ^a	2.47 ^{ab}	0.23 ^{abc}	0.25 ^a	3.18 ^a	3.30 ^{ab}	14.50 ^a	15.42 ^a
T9	2.53 ^a	2.66 ^a	0.25 ^a	0.26 ^a	3.43 ^a	3.49 ^a	15.81 ^a	16.62 ^a

T1, 0 RDF+0 ton/ha (ChM)+0 ml/L SWE; T2, 100%RDF+0 ton/ha (ChM)+0 ml/L SWE; T3, 75%RDF+0 ton/ha (ChM)+0 ml/L SWE; T4, 75%RDF+0 ton/ha (ChM)+2 ml/L SWE; T5, 75%RDF+0 ton/ha (ChM)+4 ml/L SWE; T6, 75%RDF+11.9 ton/ha (ChM)+2 ml/L SWE; T7, 75%RDF+11.9 ton/ha (ChM)+4 ml/L SWE; T8, 75%RDF+23.81 ton/ha (ChM)+2 ml/L SWE, and T9, 75%RDF+23.81 ton/ha (ChM)+4 ml/L SWE. Different alphabetical letters after values indicate significant differences at 0.05 level of significance, according to Duncan's multiple range test.

4.2 Effect of seaweed extract on tomato vegetative growth

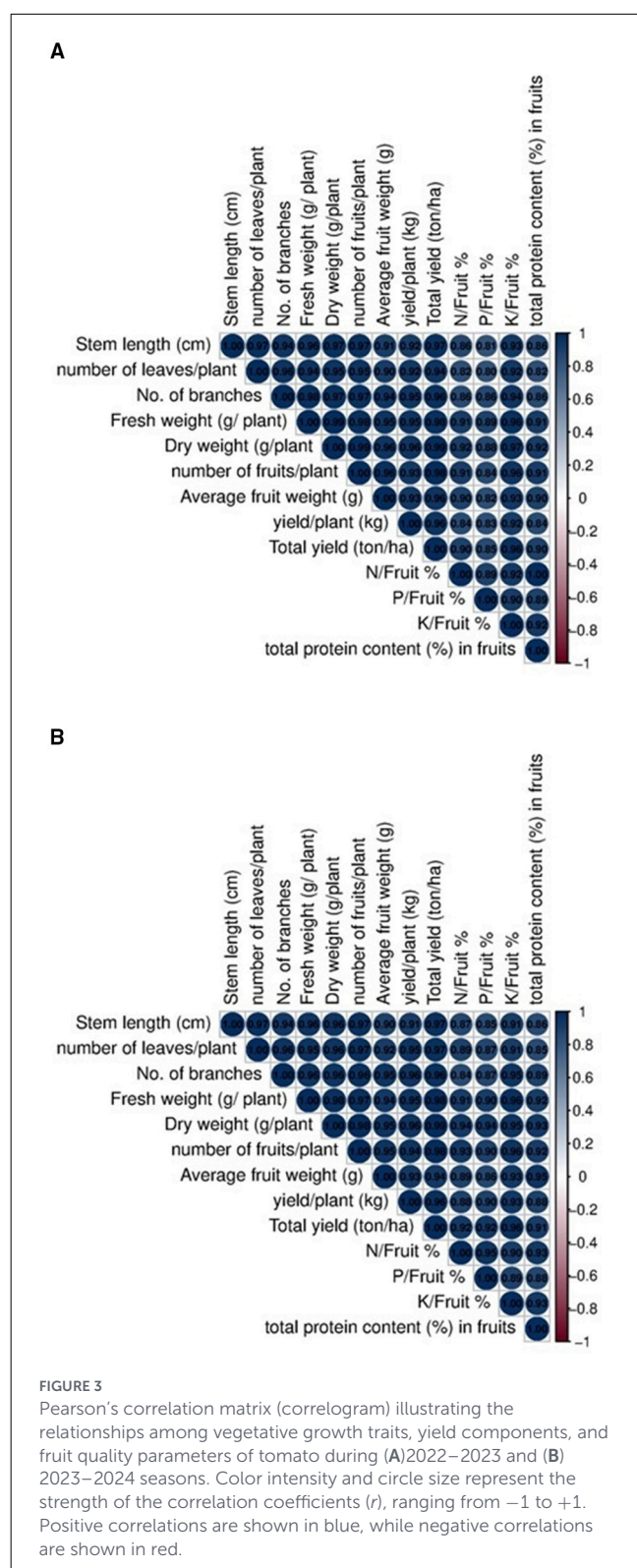
Foliar application of seaweed extract significantly improved vegetative growth traits of tomato plants, including stem length, number of leaves, number of branches, and plant biomass. These improvements were consistently observed across both seasons and became more pronounced with increasing extract concentrations (0 mL L⁻¹, 2 mL L⁻¹, and 4 mL L⁻¹), as shown in Figure 1 and Table 6. Our results are similar to those of Rouphael et al. (2017) and El Khattabi et al. (2023), who attributed the growth-promoting effects of seaweed extracts to their ability to stimulate plant physiological processes such as photosynthesis and nutrient assimilation. The stimulatory effects observed in the present study may be explained by the bioactive composition of *Ascophyllum nodosum* extracts. These extracts contain a wide range of biologically active compounds, including alginates, laminarins, fucose-rich polysaccharides, betaines, mannitol, and polyphenols, which play important roles in regulating plant metabolism and growth (Khan et al., 2009; Ahmed et al., 2022). In particular, these compounds can enhance nutrient uptake and transport by increasing root membrane permeability and stimulating nutrient transporter activity, thereby improving the assimilation of essential nutrients such as nitrogen, phosphorus, and potassium (Yadav et al., 2025). This mechanism is consistent with the enhanced vegetative growth and nutrient accumulation observed in the present experiment. Moreover, *Ascophyllum nodosum* extracts are known to regulate endogenous hormonal pathways. Rather than acting as a direct source of plant hormones, these extracts stimulate the expression of genes involved in auxin and cytokinin biosynthesis and signaling, which promotes root branching and shoot elongation (Goñi et al., 2016, 2018; Mannino et al., 2020). Such hormonal regulation likely contributed to the increases observed in stem length, branch number, and overall plant biomass, Table 6.

4.3 Response of tomato fruit productivity to fertilizer treatments

Tomato productivity in the present study responded significantly to both fertilization regimes and foliar seaweed extract application. The combined use of mineral fertilization, chicken manure, and seaweed extract resulted in higher fruit number, fruit weight, and total yield compared with the control treatment. These findings indicate that integrating organic fertilization with bio-stimulant applications can enhance nutrient use efficiency and improve productivity, Figures 1, 2. The increase in yield observed in this study may also be related to the osmoprotective and antioxidant compounds present in *Ascophyllum nodosum* extracts. These extracts are rich in betaines and polyphenols, which function as compatible osmolytes and antioxidants that help maintain cellular homeostasis and protect metabolic processes under environmental stress conditions (Craigie, 2011; Spann and Little, 2011; Elansary et al., 2016). By preserving photosynthetic activity and reducing oxidative damage, these compounds can contribute to greater biomass production and improved fruit yield, Figure 2. Furthermore, *Ascophyllum nodosum* extracts are known to activate plant defense and metabolic pathways, including the salicylic acid signaling pathway, which enhances carbohydrate metabolism and photosynthate allocation (Khan et al., 2009; Lee, 2018; Ertani et al., 2018). Increased carbohydrate synthesis and translocation to reproductive organs may therefore explain the improvements observed in fruit number and fruit weight in the present study, Figures 1, 2.

4.4 Synergistic effects of organic fertilization and seaweed extract

The combined application of chicken manure and seaweed extract produced clear synergistic effects on tomato productivity,



as shown in treatment T6, T7, T8, and T9, [Figures 1, 2](#). Organic amendments improve soil structure, stimulate microbial activity, and enhance nutrient mineralization, thereby increasing nutrient availability for plant uptake ([Liu et al., 2023](#); [Bashir et al., 2021](#)). When combined with the bio-stimulant properties of *Ascomyces*

nodosum extracts, these improvements can further enhance root activity, nutrient uptake efficiency, and overall plant performance. Maintaining a constant mineral nitrogen level while increasing organic fertilization resulted in progressive improvements in both yield and fruit quality, [Figure 2](#) and [Table 7](#). These results suggest that seaweed extract may enhance nutrient uptake efficiency and utilization, allowing partial substitution of chemical nitrogen fertilizers without compromising productivity. Such integrated fertilization strategies may therefore contribute to more sustainable tomato production systems.

4.5 Response of tomato fruit quality to different fertilizer treatments

The increases observed in nitrogen, phosphorus, potassium, and total protein contents of tomato fruits under the combined treatments are consistent with the recognized ability of *Ascomyces nodosum* extracts to enhance nitrogen metabolism and amino acid synthesis through stimulation of nitrate reductase activity, [Table 7](#). Consequently, the improved fruit nutrient composition observed in this study likely reflects both enhanced nutrient availability from chicken manure and improved nutrient assimilation efficiency resulting from seaweed extract application. In recent decades, increasing attention has been directed toward improving the nutritional quality of fresh vegetable products, whereas earlier agricultural systems primarily focused on maximizing yield ([Huang et al., 2020](#); [Tao et al., 2022](#)). With rising consumer awareness and improved living standards, the production of high quality tomatoes has become an important objective in horticultural production systems ([Souza et al., 2020](#)). Seaweed extracts are considered promising biofertilizers due to their rich composition of nutrients, amino acids, vitamins, enzymes, carbohydrates, and plant growth regulators such as auxins and cytokinins ([Kulkarni et al., 2019](#); [Drobnik et al., 2019](#); [Ammar et al., 2022](#)). These compounds enhance plant metabolism, improve mineral nutrition, and stimulate protein and amino acid synthesis. Additionally, seaweed extracts can enhance microbial activity in the soil, thereby improving soil fertility and nutrient availability ([Miceli et al., 2021](#); [Lefi et al., 2023](#)). The results of the present study also demonstrated that chicken manure significantly improved fruit quality compared with treatments without organic fertilization. Increasing rates of chicken manure significantly enhanced fruit nitrogen, phosphorus, potassium, and total protein contents ([Table 7](#)). These findings confirm that organic fertilization plays a key role in improving both tomato yield and fruit nutritional quality ([Figure 2](#); [Table 7](#)), which is consistent with previous studies conducted on tomato crops ([Santaniello et al., 2017](#); [Tao et al., 2022](#); [Lefi et al., 2023](#)).

4.6 The correlation analysis

The strong positive correlations observed among vegetative growth traits, yield components, and fruit nutrient content suggest a coordinated physiological response to the applied fertilization

treatments, [Figure 3](#). Enhanced nutrient availability, particularly nitrogen, phosphorus, and potassium, likely improved plant metabolic activity, leading to increased biomass accumulation and greater assimilate partitioning toward reproductive organs. This is reflected in the close association between plant growth parameters and yield attributes. Furthermore, the positive relationships between fruit nutrient content and total yield indicate that improved nutrient uptake efficiency played a key role in enhancing productivity. Similar findings have been reported by [Rouphael et al. \(2017\)](#), who demonstrated that bio-stimulants can improve nutrient use efficiency and promote plant growth through modulation of physiological processes. The high correlation coefficients observed in the present study may also reflect the synergistic effects of integrating organic fertilization with seaweed-based bio-stimulants, which enhance both soil fertility and plant nutrient assimilation. It is important to note that the consistently high correlations among variables indicate strong interdependence rather than redundancy, as these traits collectively contribute to plant performance and yield formation. Such relationships are commonly reported in tomato and other horticultural crops, where growth, nutrient status, and yield are tightly linked ([Bulgari et al., 2019](#)).

4.7 Study novelty and practical implications

The present study provides new evidence on the effective of integrating reduced mineral nitrogen fertilization with organic amendments and *Ascophyllum nodosum* based bio-stimulants in tomato production systems. While previous studies have demonstrated the beneficial effects of seaweed extracts or organic fertilization individually, the current research shows that combining 75% of the recommended nitrogen dose with chicken manure and foliar application of *Ascophyllum nodosum* extract can significantly improve tomato growth, yield, and fruit nutritional quality. Importantly, the results indicate that mineral nitrogen inputs can be reduced by approximately 25% without compromising yield productivity, while simultaneously improving nutrient use efficiency and fruit nutrient composition. This integrated fertilization strategy therefore represents a promising approach for reducing fertilizer and minimizing environmental impacts associated with excessive nitrogen fertilization. These findings highlight the potential of integrating organic fertilization with seaweed based bio-stimulants as a sustainable strategy for improving tomato productivity while reducing dependence on synthetic nitrogen fertilizers.

5 Conclusion

The results of this study confirm that integrating chicken manure with foliar application of *Ascophyllum nodosum* seaweed extract significantly improves tomato yield, fruit quality, and nutrient uptake. The most effective treatment was

the combination of 75% RDF with 23.8 t/ha chicken manure and foliar spraying of *Ascophyllum nodosum* extract at 4 ml/L. This approach reduced mineral nitrogen input by approximately 25% without compromising productivity, highlighting its potential as a sustainable fertilization strategy that can lower production costs and mitigate environmental risks associated with excessive mineral fertilization. The synergistic interaction between organic nutrient supply and seaweed derived bio-stimulants offers a promising pathway toward more sustainable and resource efficient tomato production systems. Further field scale validation and economic feasibility studies are recommended to support its practical application, particularly across different agro-climatic zones, along with long term soil health assessments.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding authors.

Author contributions

AALj: Conceptualization, Formal analysis, Investigation, Software, Validation, Visualization, Writing – original draft. MALm: Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft. KA: Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft. FA: Data curation, Formal analysis, Investigation, Software, Validation, Visualization, Writing – review & editing. AAla: Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Software, Validation, Visualization, Writing – review & editing. MALq: Data curation, Formal analysis, Investigation, Validation, Visualization, Writing – review & editing. EA: Conceptualization, Formal analysis, Methodology, Resources, Software, Writing – original draft. EB: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. ME: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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