Fish waste extract as a sustainable alternative to inorganic fertilizers in salad cucumber, *Cucumis sativus* cultivation: growth and yield insights

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Abstract Foliar fertilization is one of the most important methods for applying nutrients to crops. The main objective of this research was to determine the effect of the application of fish waste extract (FWE) on the growth and yield parameters of salad cucumber (*Cucumis sativus* L). Tilapia (*Oreochromis niloticus*) fish waste was mixed with brown sugar (1:1 w/w) and fermented for 21 days. Five mL filtrate was then diluted in 1 L of water. The tested treatments were: Fertilizer recommendation of the Department of Agriculture (DOA), Sri Lanka (T1), FWE of 20 % (T2), 30 % (T3), 40 % (T4), and 50 % (T5). The commercial hybrid cucumber variety 'Multistar RZ F1' seeds were germinated in germination trays filled with a topsoil and compost mixture (1:1 w/w). Two weeks old seedlings were transplanted in 30 cm x 30 cm polyethylene bags filled with topsoil media. The plants were treated with different concentrations of FWE at weekly intervals from the first week to the twelfth week as a foliar application. Post treatment assessments were taken after twelve weeks. FWE- treated plants reported significant increases in plant height (475.4 ± 2.99 cm) and number of leaves (50.5± 0.28) compared to the control, 239.3 ± 4.18 cm and 33.25 ± 0.25, respectively. Leaf dimensions were significantly larger, with leaf length and width reaching 26.87 ± 0.23 cm and 27 ± 0.2 cm in FWE-treated plants, compared to 13.87 ± 0.42 cm and 13.8 ± 0.42 cm in the control. Fresh fruit weight rose significantly to 640 ± 47.8 g in treated plants compared to 150 ± 21.2 g in the control, while fresh shoot weight increased (912.5 ± 23.6 g vs. 300 ± 20.4 g). FWE-treated plants produced a significantly higher number of fruits per plant (15 ± 0.7) compared to the control (2.75 ± 0.4). These results highlight the effectiveness of fish waste extract as a sustainable solution for enhancing cucumber growth and yield.

Keywords: fish tonic, foliar application, growth, organic farming

Introduction

In recent years, the agricultural sector has faced increasing challenges in maintaining crop productivity while minimizing environmental impact (Jagermeyr et al., 2021) As a result, there has been a growing interest in sustainable agriculture which is essential for securing long-term food supply and preserving biodiversity, closely aligning with sustainable development goals (FAO, 2019). Exploring alternative ways to replace chemical fertilizers with natural materials is an effective strategy to minimize the use of agrochemicals (Feller et al., 2012; Rumpel et al., 2020), while research into high yielding varieties within existing landraces for variety improvement (Pushpakumari & Geekiyange., 2015; Pushpakumari et al.,2017a; 2024b; 2025c) has gained increasing attention. Foliar fertilization has been identified as an effective method to supply nutrients, plant hormones, stimulants, and other beneficial compounds promoting successful growth (Fageria et al., 2009; Liu & Lal 2015,). The nutrients in the liquid form are readily available for absorption by the plant. The leaves can easily and directly absorb the nutrients through their stomatal openings and also through the epidermis (Fernandez & Brown, 2013) Foliar application offers several benefits over traditional soil-based fertilization, including improved nutrient uptake efficiency and the ability to address nutrient deficiencies (Krishnasree et al., 2021., Asadu et al., 2024). As global concerns about sustainable agriculture intensify, researchers are exploring various organic alternatives to inorganic fertilizers (Muhie, 2022; Dilshan et al., 2023; Maquen-

Perleche et al., 2023; Pushpakumari & Suthajini 2023; Jayasinghe et al., 2024; Matisic et al., 2024). One promising research avenue involves using fish waste extracts as a natural fertilizer (Madende & Hayes, 2020; Krishnani *et al*., 2022; Shama & Nimalan, 2023). Fish waste, a byproduct of the fishing industry, is rich in nutrients and organic matter, making it a potential source of plant nutrition (Caruso et al., 2020). FWE has been shown to enhance growth and yield in various crops, reporting its potential as an effective organic fertilizer. Studies have shown that the impact of FWE on different crops, including pumpkin, lettuce, finger millet, and amaranth. The results consistently indicate a positive response, with improvements in several key growth parameters such as plant height, leaf number, biomass accumulation, and overall yield (Xu & Mou, 2017; Shwe & Moe 2019; Sivasankar, 2021). Organic fertilization for salad cucumbers offers several benefits, particularly since these cucumbers are eaten raw. Organic methods minimize harmful chemical residues, reducing health risks associated with pesticide exposure, ensuring safer consumption (Baker et al., 2002; Mie et al., 2017) while enhancing soil nutrient content, leading to cucumbers richer in essential vitamins, minerals, and antioxidants (Baranski et al., 2014).

Environmentally, organic fertilizers decrease chemical runoff, improve soil health, and promote biodiversity, supporting ecological balance (Lori et al., 2017; Gamage et al., 2023).

Moreover, organically grown cucumbers often have superior taste and quality due to natural growing processes (Wang & Yu, 2021). However, the efficacy of FWES as a foliar application for specific crops such as cucumber (*Cucumis sativus L*.) requires further investigation. The main objective of this study was to determine the effects of foliar application of FWE on the vegetative growth and yield parameters of salad cucumber. By comparing different concentrations of FWE with conventional fertilization methods. This research aimed to identify an optimal and economical rate for cucumber cultivation. The findings of this study have important implications for developing eco-friendly farming systems and reducing the environmental footprint of cucumber cultivation. Furthermore, this research aligns with global efforts to promote circular economy principles in agriculture by repurposing fish waste into valuable agricultural inputs.

Materials and methods

Experimental Location

The experiment was conducted at a protected house in the Department of Botany, Faculty of Science, Eastern University, Sri Lanka, which is located at the latitude of 7^0 47' 47.1" N and the longitude of 81^0 34'56.9" E (DL2b). The variation of average mean temperature and rainfall from 28.3 °C and 0.11mm to 30.5 °C and 2.73mm during the experimental period from March 2023 to September 2023.

Preparation of fish waste extraction

The Tilapia (*Oreochromis niloticus*) fish waste (including heads, bones, skin, fins, and viscera) was collected from the Batticaloa fish market. The waste was chopped and mixed with brown sugar in a 1:1 w/w ratio. Brown sugar was added as an energy source, and the mixture was kept for 21 days for fermentation (Shama & Nimalan 2023). Then the solution was filtered using 0.5 mm fine sieve, and 5 mL of the filtrate was diluted in 1 L of distilled water. This diluted solution was then used as the base to prepare different treatment concentrations. To prepare the 20% concentration, 200 mL of the base solution was mixed with 800 mL of distilled water to make a total volume of 1 L. Similarly, for the 30% concentration, 300 mL of the base solution was mixed with 700 mL of distilled water, while the 40% and 50% concentrations were prepared by mixing 400 mL and 500 mL of the base solution with 600 mL and 500 mL of distilled water, respectively.

Experimental design

A Completely Randomized Design (CRD) was employed to experiment, including five treatments and a control. T1- DOA recommended fertilizer dosage for cucumber cultivation (T1) (Table 1); T2- 20% of FEW, T3- 30% of FEW, T4- 40% of FEW, T5- 50% of FWE and control without any fertilizer application. Each treatment had five replications. The commercial hybrid cucumber variety 'Multistar RZ F1' seeds were germinated in germination trays filled with a topsoil and compost mixture (1:1 w/w ratio).

The trays were kept under natural environmental conditions for germination. Once germinated, the seedlings were transplanted into 30 cm x 30 cm polyethylene bags filled with topsoil media. All the agronomic practices were followed according to the recommendations of DOA, Sri Lanka.

Table 1: Fertilizer recommendation given by DOA

Time of application	Urea kg/ha	TSP kg/ha	MOP kg/ha
Basal	75	200	60
After 4 weeks	75	–	60
After 5 weeks	75	–	60

Nutrient analysis

Measurement of pH

The pH of the fish waste extraction solution was measured using a digital pH meter. A representative 20 mL sample of the fish waste solution was stirred thoroughly to achieve homogeneity. Before measurement, the pH meter was calibrated using standard buffer solutions (pH 4.0, 7.0, and 10.0).

Electrical Conductivity (EC)

The 20 mL of the solution was mixed thoroughly to ensure uniformity, and the EC electrode was immersed in the solution. EC was recorded once the reading stabilized.

Available N, P and K

Available nitrogen in the fish waste extraction solution was quantified using the Micro-Kjeldahl Method as described by Jackson (1973). The potassium content was determined following Jackson's (1973) protocol. Ten mL of the solution was analyzed using a spectrophotometer (Thermoscienific, GENESYS 50 UV -Visible Spectrophotometer) calibrated with standard potassium solutions. Total phosphorus was measured using colorimetry based on Jackson's (1973) method. A 10 mL of fish waste extraction solution was digested with nitric acid to release phosphorus. The digest was reacted with ammonium molybdate and ascorbic acid to form a blue-coloured molybdenum-phosphate complex. The intensity of the blue colour was measured flame photometer with a K filter. The phosphorus concentration was calculated from a standard colour development curve.

Application of treatments

The cucumber plants were subjected to foliar application of FWE at 20%, 30%, 40% and 50% concentrations weekly over 12 weeks. The FWE was applied using a spray bottle to ensure uniform coverage. During the first week, 5 mL of FWE was applied per plant, which was increased to 10 mL in the second week. From the third week onward, the application volume was increased to 20 mL per plant per week. All treatments were consistently carried out at 9:00 am to minimize environmental variability and enhance absorption efficiency.

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Data collection

Plant height (cm) was measured starting from the base of the stem to the tip of the highest leaf by using a measuring tape and ruler in unit cm as per the method used by Grant and Todd (2001). The Number of leaves (NL), length, and width of leaves (cm) were collected as vegetative parameters at one-week intervals up to 12 weeks. Cucumber harvesting was started 45 days after germination. Cucumber fruits were harvested at weekly interval of up to 12 weeks. Fruits were ready for harvest in seven days after flowering. Fresh weight of the fruit (FWF) (g), Number of fruits per plant (NSP), and Fresh shoot weight (FSW) (g), were measured. Data was subjected to statistical analysis ANOVA using the Minitab statistical software at a 5% significant level. The mean separation was done with Tukey's Test.

Results and Discussion

Comparison of chemical properties of fish waste extraction values with SLSI Standard Values

The chemical properties of the FWE were evaluated against the Sri Lanka Standards Institution (SLSI) guidelines to determine its suitability for agricultural use. The pH value of 7.32 is well within the acceptable range of 6.5 to 8.5, indicating a neutral to slightly alkaline condition, suggesting a low salinity level safe for crops. Nutrient analysis reveals that FWE contains 1.37% nitrogen, 0.98% phosphorus, and 1.4% potassium (Table 2). These values exceed the SLSI minimum required standards of 1%, 0.5%, and 0.5%, respectively. It significantly indicates the rich nutrient profile pile up in FWE. The high nitrogen content supports vigorous vegetative growth, while the phosphorus and potassium levels are adequate for root development and overall plant health. The FWE meets all the required SLSI standards for available N, P, and K, pH and EC, confirming its potential as a beneficial and safe agricultural input.

Table 2: Nutrient analysis of FEW

Treatment	pH	EC (ds/m)	N%	P%	K%
SLSI standard	6.5-8.5	<20	>1%	>0.5%	>0.5%
FWE	7.32	2.45	1.37%	0.98%	1.4%

Effect of FWE on plant height

The application of different concentrations of FWE affects plant height while observing the significant differences among the treatments from the third to the twelfth weeks after planting (WAP) ($P < 0.05$) (Table 3). In the third week, the mean plant height ranged from 37.7 ± 0.75 cm (control) to 102.05 ± 1.43 cm (30% of FWE), indicating distinct growth patterns across treatments. By the sixth week, the control showed the least growth at 130.4 ± 4.68 cm, while 30% of FWE had the highest plant height at 287.7 ± 1.62 cm. Different concentrations of 20%, 30%, 40%, and 50% of FWE exhibited significantly greater plant heights than the control, suggesting these treatments could effectively promote early growth. In the ninth week, the control continued to have the lowest height at 194.4 ± 2.4 cm, whereas the treatment of 30% of FWE showed the highest growth at 389.07 ± 2.12 cm. The application of FWE at different concentrations of 30%, 40%, and 50% resulted in significantly greater plant height compared to both the T1 treatment and the control. By the twelfth week, the control had the lowest plant height at 239.3 ± 4.18 cm, while the treatment of 30% FWE again showed the maximum growth at 475.4 ± 2.99 cm. Treatments of 30%, 40%, and 50% of FWE consistently reported higher plant height over time. The results indicated that 30%, 40%, and 50% of FWE treatments were the most effective in increasing plant height over the study period. The control consistently resulted in the shortest plant height, suggesting it was the least effective treatment. The increasing plant height over the weeks reports a clear and consistent trend of treatment efficacy, particularly highlighting the superiority of 30% of FWE treatments in achieving maximum plant height.

Table 3. Foliar application of FWE on average plant height (cm).

Treatment	03 WAP	06 WAP	09 WAP	12 WAP
Control	37.7 ± 0.75^{d}	130.4 ± 4.68^{d}	194.4 ± 2.4^{d}	239.3 ± 4.18^{d}
T1	69.12 ± 0.67^{c}	221.4 ± 4.72^{c}	306.3 ± 3.27^{c}	359.25 ± 3.9^{c}
T2	88.2 ± 1.45^{b}	262.4 ± 4.86^{b}	358.6 ± 3.3^{b}	428.6 ± 3.39^{b}
T3	102.05 ± 1.43^{a}	287.7 ± 1.62^{a}	389.07 ± 2.12^{a}	475.4 ± 2.99^{a}
T4	100.1 ± 0.99^{a}	287.4 ± 2.62^{a}	383.2 ± 2.85^{a}	465.5 ± 3.04^{a}
T5	96.9 ± 2.91^{a}	283.1 ± 2.4^{a}	386.2 ± 3.1^{a}	467.4 ± 1.78^{a}
P value	0.000	0.000	0.000	0.000

*.*Means followed by the same letter in each column are not significantly different at the 0.05 % level. (T1- DOA recommended fertilizer dosage, T2-20% of FWE, T3- 30% of FWE, T4-40% of FWE , T5-50% of FWE)*

The results indicate that the 30%, 40%, and 50% FWE treatments significantly increased plant height compared to the control. This suggests that the control was the least effective treatment for promoting growth. Among the tested concentrations, the 30% treatment produced the maximum plant height, demonstrating a clear and consistent trend of treatment efficacy. These findings align with Shama and Nimalan (2023) who reported increased plant height in chili plants treated with yellowfin tuna waste extract. Similarly, Srikumaran et al. (2017) observed that different concentrations of fish waste solution significantly enhanced okra growth compared to chemical treatments, while Khandaker et al., (2017) noted increased cucumber vine length with the application of fish waste extract. Arani et al. (2023) reported that a mixture of 50% fish extract combined with 50% banana extract resulted in the highest plant height in green chilli plants. Furthermore, Mohammad et al. (2018) revealed that the application of 20 mL of fish waste extract significantly enhanced vine length, leaf count, chlorophyll content, and stomatal conductance in cucumber plants when compared to the control. The present study's results are consistent with these findings, showing a statistically significant association between different concentrations of FWE and increased plant height, confirming the potential of organic fish waste extracts as effective growth promoters.

Effect of FWE on the average number of leaves (NL)

There is a significant variation in the average NL as affected by different concentrations of FWE ($P < 0.05$) (Table 4). In the third week, there is a significant difference in NL ($P<0.05$). Control shows the lowest NL (7.5 ± 0.28) and 30% of FWE shows the NL (10.25 ± 0.47) in third week. The fertilizer recommendation given by DOA (T1), 20% (T2), 30% (T3), 40% (T4), and 50% (T5) have significantly more leaves compared to the control. Treatments show their effectiveness, with 30%, 40%, and 50% of FWE promoting more leaf growth. The treatments significantly affected the leaf production. The 30%, 40%, and 50% of FWE continue to produce a higher number of leaves. The 30% of FWE produces the highest NL (50.5 ± 0.28) in the twelfth week followed by other treatments. The FWE of 30% is the most effective treatment for increasing NL, followed closely by 40% and 50%, of FWE with control being the lowest. Over the experiment, treatments 30% (T3), 40% (T4), and 50% (T5) have consistently resulted in a higher number of leaves compared to T1 and the control. Supporting these findings, (Ramesh et al., 2020) reported that fish wastewater enhances leaf production in Amaranth (*Amaranthus* sp *L*.), highlighting the effectiveness of fish-based fertilizers in stimulating vegetative growth. Additionally, (Mahdavi et al., 2024) reported that fish waste bio-fertiliser mitigates the effects of salinity stress by enhancing plant growth and reducing stress markers, particularly at high salinity levels, underscoring the versatility of fish-based fertilizers under various environmental conditions. Further Kannangara and Ranasinghe (2021) noted that fertilizers formulated with fish waste when combined with decomposed plants and hydrolyzed using *Carica papaya*, significantly increased nitrogen (0.57%) and phosphorus (0.06%) content, promoting the growth of *Centella asiatica* and *Basella alba*. Johari et al. (2020) reported that the application of Fish Amino Acid (FAA) and the different sampling times had a significant impact on the shoot length of okra. Furthermore, the volume of FAA significantly influenced soil pH, while the number of weeks significantly affected soil moisture content. These findings collectively support the potential of fish waste-based bio-fertilizers as a sustainable and effective alternative to conventional fertilizers, enhancing leaf growth and overall plant health under diverse agricultural settings.

Table 4. Foliar application of FWE on average number of leaves

Treatment	03WAP	06WAP	09WAP	12WAP
Control	7.5 ± 0.28^{b}	16.5 ± 0.28^{c}	24.7 ± 0.25^{d}	33.25 ± 0.25^{e}
T1	9 ± 0.4^{ab}	23.25 ± 0.25^{b}	32 ± 0.4c	42.25 ± 0.25^{d}
T2	10 ± 0.4^{a}	24.5 ± 0.64^{a}	34.7 ± 0.75^{b}	45 ± 0.4^{c}
T3	10.25 ± 0.47^{a}	25.25 ± 0.25a	37.2 ± 0.47^{a}	50.5 ± 0.28^{a}
T4	9.5 ± 0.64^{ab}	25 ± 0.4^{a}	36 ± 0.4^{ab}	48 ± 0.0^{b}
T5	10 ± 0.4^{a}	24.74 ± 0.25^{ab}	36.5 ± 0.64^{ab}	47.2 ± 0.47^{b}
P value	0.004	0.000	0.000	0.000

.*Means followed by the same letter in each column are not significantly different at the 0.05 % level. (T, T1- DOA recommended fertilizer dosage, T2-20% of FWE, T3- 30% of FWE, T4-40% of FWE , T5-50% of FWE)*

Effect of FWE on leaf length

The results revealed that FWE foliar applications significantly affect leaf length over 12 weeks, with consistent differences among treatments. At the third WAP, the control had the shortest leaves (4.3 ± 0.12 cm), while 30% of FWE had the longest Leaves (7.75 ± 0.14 cm). By the sixth WAP, the control continued to lag (8.12 ± 0.23 cm), whereas treatments 40% and 50% of FWE showed the greatest leave length (14.37 ± 0.12 and 14.5 ± 0.2 cm) respectively. At 9 WAP, the control remained the shortest (10.3 ± 0.37 cm), while 30% of FWE exhibited the highest growth (19.5 ± 0.2 cm). At 12 WAP, the control had the smallest leaf length (13.87 ± 0.42 cm), with 30% of FWE again achieving the maximum length (26.87 ± 0.23 cm). The treatments 30%, 40%, and 50% of FWE consistently produced significantly longer leaves compared to the control, with the 30% concentration being particularly effective across all intervals (Table 5). These findings underscore the efficacy of FWE, especially at 30%, 40%, and 50% of FWE concentrations, in enhancing leaf growth.

Table 5. Foliar application of FWE on average leaf length (cm)

Treatment	03WAP	06WAP	09WAP	12WAP
Control	4.3 ± 0.12^{d}	8.12 ± 0.23^{d}	10.3 ± 0.37^{c}	13.87 ± 0.42^{d}
T1	6.2 ± 0.14^{c}	12.37 ± 0.12^{c}	15.7 ± 0.66^{b}	20.2 ± 0.59^{c}
T2	7 ± 0.2^{b}	13.25 ± 0.14^{b}	17 ± 0.2^{b}	22.8 ± 0.42^{b}
T3	7.75 ± 0.14^{a}	14.37 ± 0.12^{a}	19.5 ± 0.2^{a}	26.87 ± 0.23^{a}
T4	7.6 ± 0.12^{ab}	14.5 ± 0.2a	18.6 ± 0.23^{a}	25.75 ± 0.14^{a}
T5	7.5 ± 0.2^{ab}	14.5 ± 0.2^{a}	18.75 ± 0.14^{a}	25.5 ± 0.1^{a}
P value	0.000	0.000	0.000	0.000

. **Means followed by the same letter in each column are not significantly different at the 0.05 % level.*
(T1- DOA recommended fertilizer dosage, T2-20% of FWE, T3- 30% of FWE, T4-40% of FWE , T5-50% of FWE)

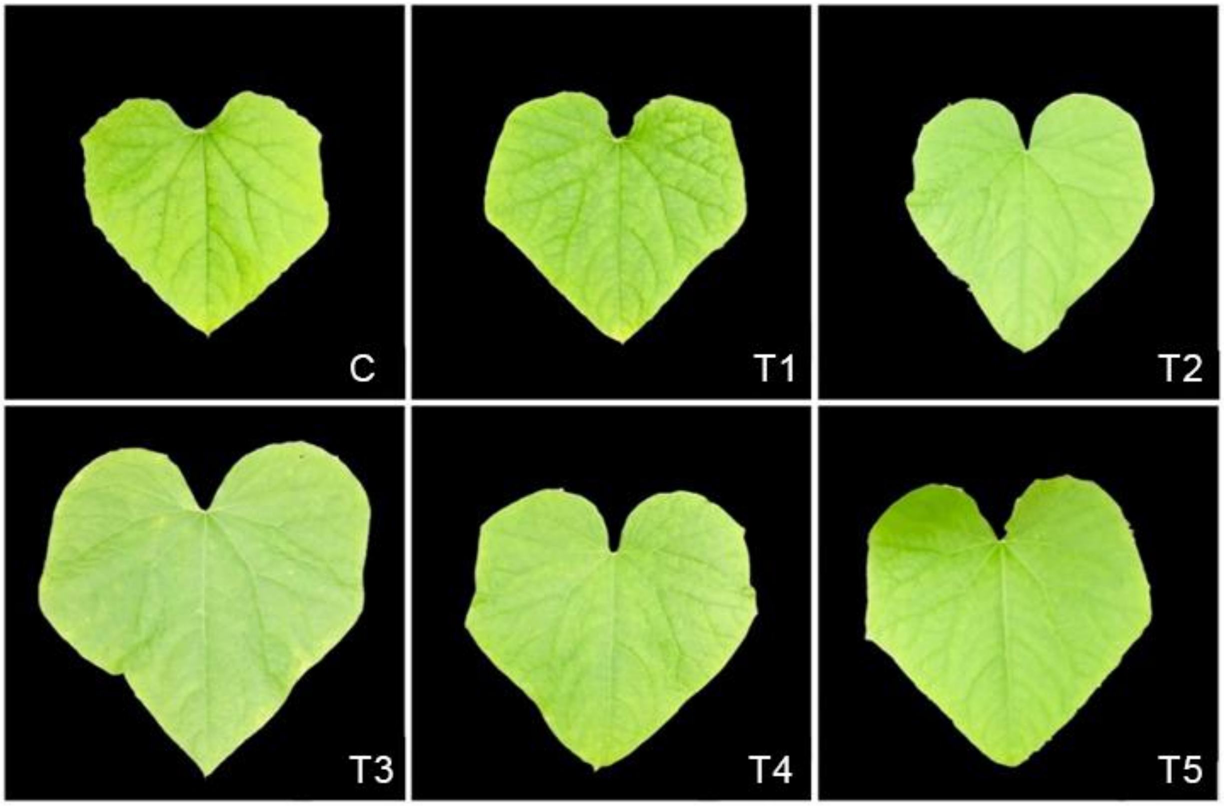

Figure 1: Visual comparison of leaf morphology in salad cucumber (*Cucumis sativus* L.)

*(*C- Control, T1- DOA recommended fertilizer dosage, T2-20% of FWE, T3- 30% of FWE, T4-40% of FWE, T5-50% of FWE)*

Effect of FWE on leaf width

The results indicated the effect of different concentrations of FWE on the leaf width of salad cucumber over 12 weeks, revealing statistically significant variations among the treatments each week ($p<0.05$). At 3 weeks WAP, the control exhibited the smallest leaf width (4.2 ± 0.14 cm), whereas 30% of FWE had the largest (7.8 ± 0.12 cm). By the sixth WAP, the control plants showed the least growth (8.1 ± 0.23 cm), while treatments 40% and 50% of FWE achieved the highest leaf width (14.5 ± 0.2 cm). At 9 WAP, the control remained the smallest (10.2 ± 0.32 cm), and 30% of FWE displayed the greatest width (19.5 ± 0.2 cm). At 12 WAP, the control had the smallest leaf width (13.8 ± 0.42 cm), with 30% of FWE reporting the maximum leaf width (27 ± 0.2 cm) (Table 6).

The results indicated that treatments 30%, 40%, and 50% of FWE were significantly more effective in increasing leaf width than the control. Interestingly, the 30% FWE concentration consistently resulted in the highest leaf width across all intervals (Figure 1)

These findings underscore the efficacy of FWE, particularly at 30%, 40%, and 50% of FWE concentrations, in enhancing leaf growth, suggesting its potential as a valuable foliar application for improving leaf development in salad cucumber plants.

Table 6. Foliar application of FWE on average leaf width (cm)

Treatment	03WAP	06WAP	09WAP	12WAP
Control	4.2 ± 0.14^{d}	8.1 ± 0.23^{d}	10.2 ± 0.32^{c}	13.8 ± 0.42^{c}
T1	6.1 ± 0.12^{c}	12.3 ± 0.12^{c}	15.6 ± 0.65^{b}	20.2 ± 0.59^{b}
T2	7.0 ± 0.2^{b}	13.2 ± 0.14^{b}	17.0 ± 0.2^{b}	22.8 ± 0.42^{b}
T3	7.8 ± 0.12^{a}	14.3 ± 0.12^{a}	19.5 ± 0.2^{a}	27.0 ± 0.2^{a}
T4	7.6 ± 0.2^{ab}	14.5 ± 0.2^{a}	18.6 ± 0.23^{a}	25.7 ± 0.14^{a}
T5	7.5 ± 0.2^{ab}	14.5 ± 0.2^{a}	18.7 ± 0.14^{a}	25.7 ± 0.14^{a}
P value	0.000	0.000	0.000	0.000

**Means followed by the same letter in each column are not significantly different at the 0.05 % level. (T1- DOA recommended fertilizer dosage, T2-20% of FWE, T3- 30% of FWE, T4-40% of FWE, T5-50% of FWE)*

Impact of FWE on Yield Parameters

Fresh Fruit Weight (FFW)

The study assessed the effect of foliar application of FWE on the average FFW of salad cucumber over 12 weeks, with measurements taken at 3, 6, 9, and 12 WAP. There was no significant difference among treatments in the 8th week ($P > 0.05$), with mean FFW ranging from 20 ± 20 g (control) to 102.5 ± 7.5 g (30% of FWE). From the ninth week to the twelfth week, significant differences were observed ($P < 0.05$).

The 30% of FWE consistently had the highest FFW: 225 ± 67.6 g at 9 WAP, 442.5 ± 57 g at 10 WAP, 562.5 ± 33 g at 11 WAP, and 640 ± 95 g at 12 WAP. Other treatments also showed increased weights compared to the control, but 30% of FWE reported the most significant highest FFW (Figure 2 and Figure 3a).

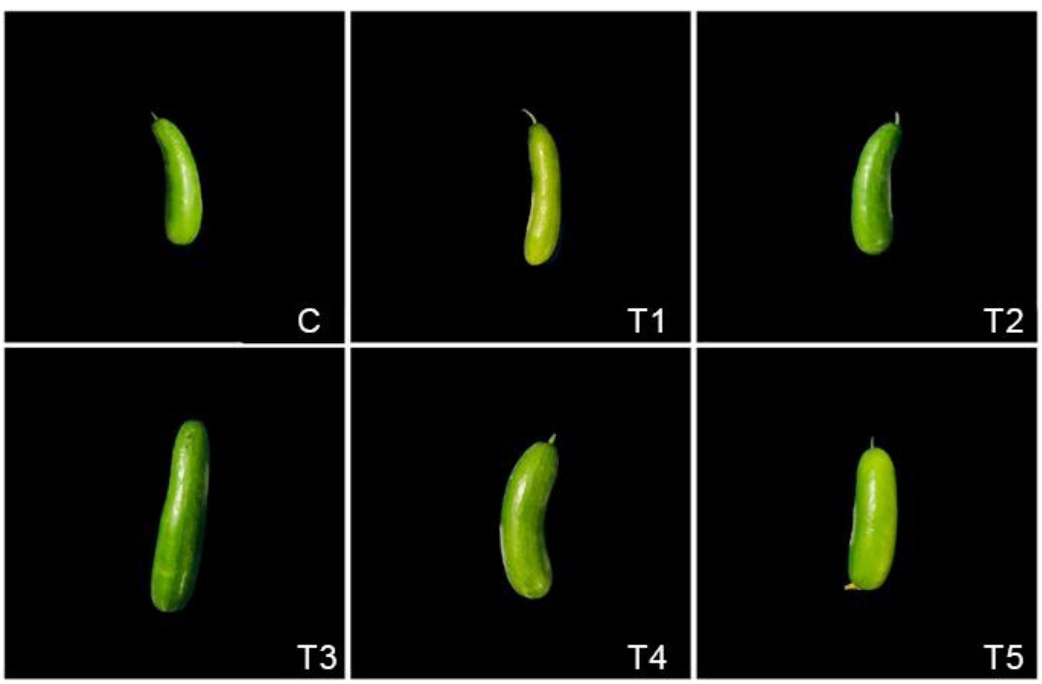

Figure 2: Effect of different concentrations of FWE on selected hybrid cucumber variety

*(*C- Control, T1- DOA recommended fertilizer dosage, T2-20% of FWE, T3- 30% of FWE, T4-40% of FWE , T5-50% of FWE)*

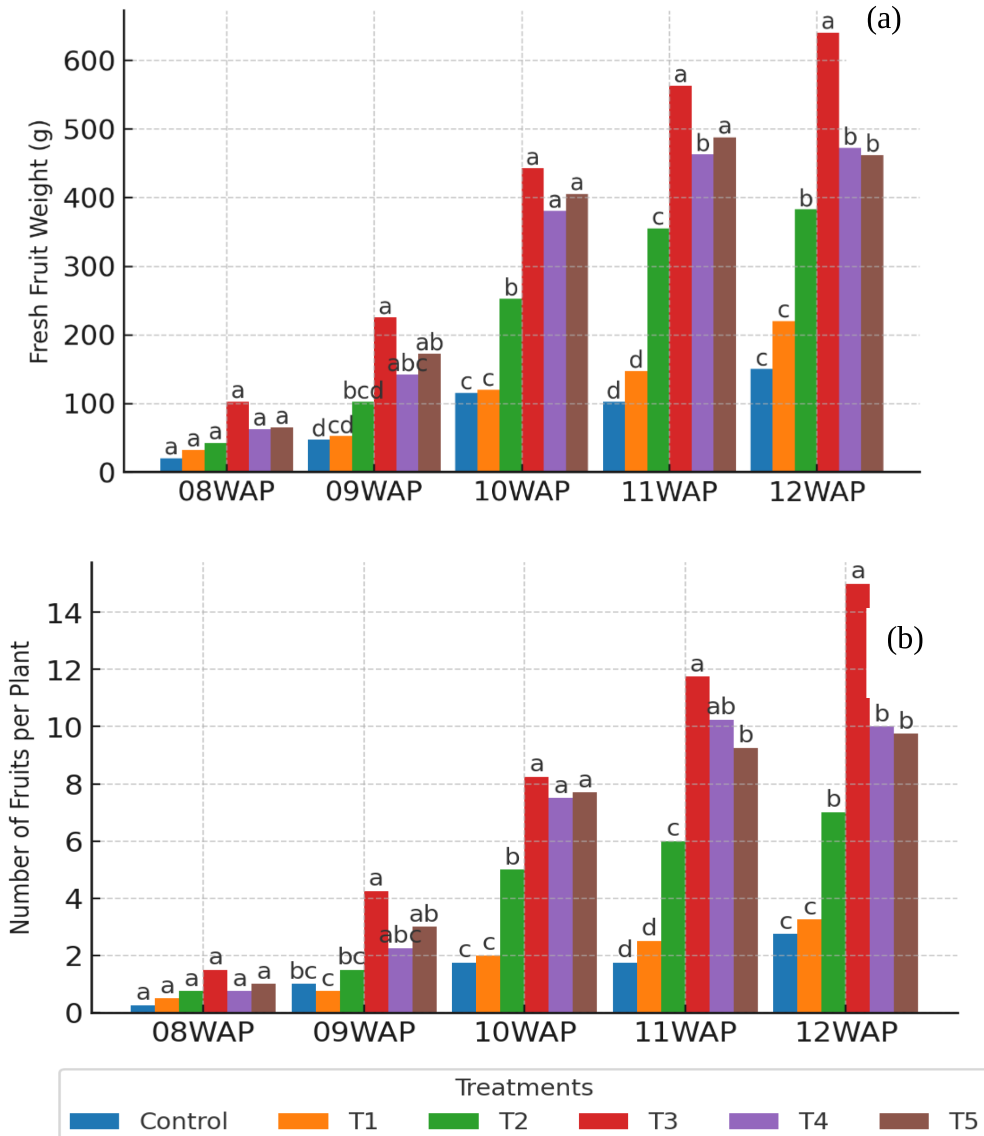

Figure 3: Variation in Yield Parameters of Salad Cucumber (*Cucumis sativus* L.) with Different concentrations of FWE.
*(*a- Fresh Fruit Weight, b-Number of fruits per plant*

Number of fruits per plant (NSP)

The application of different concentrations of FWE resulted in statistically significant variations in the number of fruits per plant-NSP. According to Figure 3b, no significant difference was observed among treatments in the 8th week ($P > 0.05$), with the NSP ranging from 0.25 ± 0.2 (control) to 1.5 ± 0.2 (30% of FWE). Significant differences were evident from the ninth week onwards ($P < 0.05$). In the 9th week, 30% of FWE treatment had the highest NSP (4.25 ± 1.7), increasing to 8.25 ± 1.25 at 10 WAP, 11.75 ± 1.5 at 11 WAP, and 15 ± 1.14 at 12 WAP. Treatments of 40% and 50% of FWE also showed significant increases in the NSP, but 30% of FWE remained the most effective throughout the period (Figure 3b).

Fresh shoot weight (FSW)

FSW is affected by different concentrations of the tested FWE. There were significant differences among treatments at 12 WAP ($P < 0.05$). The 30% FWE treatment reported the highest FSW of 912.5 g, while the 40% and 50% FWE treatments reported 850 g and 837 g, respectively. The control had the lowest FWE at 300 ± 20.4 g. These results indicate that treatments 30%, 40%, and 50% of FWE significantly enhanced fresh shoot weight compared to the control (P<0.05%) (Figure 4).

The results indicated that the application of FWE, particularly at concentrations of 30%, 40% and 50%, significantly improves the yield parameters of salad cucumber. The 30% FWE treatment consistently reported great performance across all parameters, including FFW, NSP, and FSW. The 30% FWE treatment reported the highest FFW (640 ± 95 g at 12 WAP), NSP (15 ± 1.14 at 12 WAP), and the greatest FSW (912.5 ± 23.6 g at 12 WAP).

These results are aligned with recent research highlighting the efficacy of organic fertilizers derived from fish waste in promoting plant growth and enhancing yield. For example, studies have shown that biofertilizers made from fish waste can significantly increase the biomass of various crops by providing a rich source of nitrogen and other essential nutrients (Jose et al., 2023). This increased nutrient availability supports enhanced photosynthetic activity and plant vigour, leading to greater fruit and shoot development (Lin et al., 2024). Additionally, fish-based fertilizers have been reported to improve soil microbial activity, which further enhances nutrient uptake efficiency and plant health (Rajeswari et al., 2018). Reports indicated that the amino acids and growth-promoting substances in fish waste extracts can stimulate root development and improve stress tolerance, contributing to increased fruit production and plant development (Buang et al., 2018). The consistency of the 30% of FWE treatments in achieving the highest yield parameters sug1gests that this concentration optimally balances nutrient supply without causing toxicity or over-fertilization effects, making it a promising approach for sustainable agriculture. Zhang et al. (2021) highlighted that the fruit quality of cucumber plants is influenced by environmental factors, emphasizing the importance of utilizing biotechnological tools in breeding programs to support sustainable agriculture.

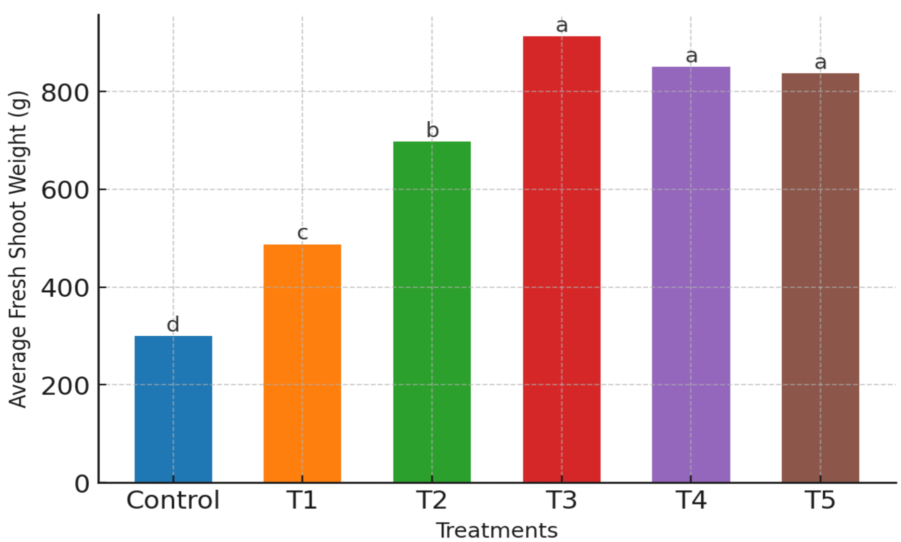

Figure 4: Variation of fresh shoot weight of salad cucumber (*Cucumis sativus* L.) with different concentrations of FEW after 12 weeks of transplanting

Effect of fish waste extract on root growth and development

The results revealed significant differences in fresh root weight across the treatments (p<0.05). The 30% FWE (T3) treatments exhibited the highest fresh root weight, recorded at 57.5 ± 1.4 g**,** which is statistically significant compared to other treatments. This suggests that the 30% concentration of FWE optimally promotes root biomass in salad cucumber (*Cucumis sativus* L.), improving overall plant growth and nutrient uptake. The second and third highest fresh root weights were observed in the 40% (T4) and 50% (T5) of TWE treatments, with values of 52.5 ± 1.4 g and 51.2 ± 3.15 g**,** respectively. Although these treatments also showed increased root weight compared to the control, the 30% FWE concentration provided the most effective results. This may be related to the balanced nutrient supply and the bioactive compounds in fish waste extracts, which can stimulate root development. Previous studies support these findings, demonstrating the positive impact of fish-based organic fertilizers on root biomass. Ekinci et al. (2019) reported a 123.9% increase in fresh root weight in spinach when fish manure (FM) was applied. This aligns with the present study, suggesting that fish-based extracts promote vigorous root systems across different crops. Another study observed enhanced fresh and dry root weights in okra plants following the application of Fish Amino acids, further reinforcing the efficacy of fish waste products in improving root growth (Kavitha et al., 2020). The enhanced root biomass in these studies may be attributed to the nutrient-rich composition of fish waste products, including nitrogen, phosphorus, and potassium, essential micronutrients, and organic matter that improve soil fertility and plant nutrient absorption. The increase in fresh root weight could also result from improved soil aeration and microbial activity stimulated by the fish waste extract, which enhances root expansion and proliferation.

Conclusion

The study underscores the growing importance of using fish waste-derived organic fertilizers in sustainable agriculture and organic farming as a viable alternative to conventional chemical fertilizers. Statistically significant differences ($P<0.05$) were observed across various growth parameters, indicating the effectiveness of these treatments. FWE-treated plants reported significant increases in plant height (475.4 ± 2.99 cm) and number of leaves (50.5 ± 0.28) compared to control 239.3 ± 4.18 cm and 33.25 ± 0.25 respectively. Leaf dimensions were significantly larger, with leaf length and width reaching 26.87 ± 0.23 cm and 27 ± 0.2 cm in FWE-treated plants, compared to 13.87 ± 0.42 cm and 13.8 ± 0.42 cm in the control. Fresh fruit weight rose significantly to 640 ± 47.8 g in treated plants versus 150 ± 21.2 g in the control, while fresh shoot weight increased (912.5 ± 23.6 g vs. 300 ± 20.4 g). Additionally, FWE-treated plants produced significantly more fruits per plant (15 ± 0.7) compared to the control (2.75 ± 0.4). This concentration optimises growth and yield and provides a sustainable and environmentally friendly solution, utilizing readily available fish waste to address fertilizer shortages while promoting healthy and safe cucumber production. Future studies should focus on assessing the long-term impacts of fish tonic treatments and exploring their applicability to other plant species to further support sustainable agricultural practices

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Conflicts of interest

The authors declare that they have no conflict of interest.

Author Contribution

W.M.A.P. Wijesundara contributed to data collection, analysis, and drafting of the manuscript. E.U.U. Rathnathunga was involved in developing the methodology and editing the manuscript. W.H.D.U. Pushpakumari contributed to the research concept, research planning, methodology design, and supervision of the research study.

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