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The effect of mixed fertilizers on the vegetative growth and reproductive characteristics of tomatoes (*L. esculentum* Mill)

Abstract. The purpose of this study was to investigate how combination fertilizers based on seaweed liquid extract (SLF) and nitrogen fertilizer (PU) affected tomato vegetative development and reproductive characteristics (*L. esculentum* Mill). The mixed fertilizers had varying amounts of SLF and a constant amount of PU [(5% SLF + PU50), (10% SLF + PU50, 30% SLF + PU50), and (50% SLF + PU50)]. The greenhouse was used to study tomato growth and yield response to mixed fertilizer. The Randomized Complete Block Design (RCBD) was used for the experiment, with five replicates for each treatment. The data were analysed using variance analysis (ANOVA) and compared to a control that did not use fertilizer. The results revealed that the mixed fertilizers resulted in substantial increases in all the evaluated attributes. However, mixed fertilizer (10% SLF + PU50) produced the highest vegetation, flower, and fruit characteristics compared to the control plants and other treatments. These results clearly show that 10% SLF + PU50 is favourable for tomatoes.

Key words: tomato, fertilizer, vegetative, growth.

Introduction

Tomatoes (*Lycopersicon esculentum* Miller) are one of the most significant vegetable crops farmed in the world, both in the field and in greenhouses [1]. In terms of human health, tomato is a vital source of minerals, vitamins, and antioxidants and is a substantial component of many people's daily diets in many countries [2,3]. Using seaweed in such a circumstance is thus a financially advantageous proposition. Seaweed is used as a foliar spray or a soil drench to promote faster growth and production in leafy vegetables, fruits, orchards, and horticultural plants. The presence of plant hormones, particularly cytokinin, has been attributed to a large portion of the benefit derived from the use of seaweed extract.

Various seaweed concentrates contain considerable amounts of cytokinin in addition to other phytohormones [4]. Meanwhile, nitrogen fertilizer is critical for plant growth and final grain yield, and it has been applied at the optimal rate to meet the plant's needs. Urea is one of the most popular nitrogenous fertilizers among farmers due to its high nitrogen content (46% by weight), which has overtaken other nitrogenous fertilizers. When urea fertilizer inputs to the soil system exceed crop needs, 50% of the applied fertilizer may escape to the environment owing to leaching, surface runoff, decomposition, and ammonium volatilization in the soil, since only a part is absorbed by plants.

The slow-release method was used on urea fertilizer to gradually release the nutrient contents and to correspond with the usage efficiency of plant uptake. It had been reported that PVA was used for seed coating or pre-treatment seed to improve seed germination, seedling growth, or salt resistance [5,6], or used in soil to reduce runoff and soil losses [7], improve root number and root length in jujube [8], and improve rooting percentage in woad and pear clones [9,10]. Copper encapsulated in chitosan and PVA-chitosan increases the development characteristics of tomato plants, according to Hipólito et al. [11] and Pinedo et al. [12]. As a result, the combination of hydrogel and fertilizer has emerged as one of the promising materials for overcoming the shortcomings of conventional fertilizer by significantly improving plant nutrition, decreasing fertilizer loss rate, reducing environmental impact from water-soluble fertilizer, supplying nutrients sustainably, and lowering irrigation frequency [13]. Mixed fertilizers have the potential to increase crop production stability, maintain improvements in soil fertility, and improve plant development efficiency [14]. Copper encapsulated in chitosan and PVA-chitosan hydrogel, according to Hipólito et al. [11] and Pinedo et al. [12], increases the growth characteristics of tomato plants and plants and pepper.

Evidence suggests that combining organic and inorganic fertilizers improves nutrient availability, optimizes the soil environment, and improves crop productivity [15,16]. The combined use of chemical and organic sources, known as integrated nutrient management, is generally acknowledged as a method of enhancing crop productivity sustainably [17,18]. When compared to NPK fertilizer alone, a combined application of 3 t/ha vermicompost and 50% doses of NPK (60: 30: 30: kg/ha) fertilizer resulted in greater tomato crop growth and yield [19].

Ayeni et al. [20] found that poultry at 20, 30, and 40 t/ha with NPK 15: 15: 15 fertilizers greatly increased plant leaf area, quantity of leaves, branches, and tomato fruit yield. Adnan et al. [21] discovered a significant increase in plant growth and tomato fruit yield because of using organic manures in combination with the recommended dose of inorganic fertilizers. Makinde and Ayoola [22] found that applying a mix of synthetic fertilizers to maize (*Zea mays L.*) yielded higher yields than manure alone. According to Akanbi et al. [23], a combined application of 4 t/ha maize straw compost and N mineral fertilizer at 30 kg/ha increased plant growth and gave higher tomato yield. Dawa et al. [24] discovered that fertilizing tomato plants with mixed fertilizers chicken manure at 6 ton/fed with 50% NPK from the recommended dose, i.e., 75 N, 35 P_2O_5, and 85.5 K_2O kg/fed and sprayed with seaweed extract at a rate of 2.5 mL/L produced the highest values of vegetable growth parameters, chlorophyll, N, P, and K percentages in tomato leaves. Pepper plants fed with mixed fertilizers (seaweed extract and chicken manure as organic fertilizers) in the presence of biofertilizers enhanced vegetative plant growth and NPK percentages in leaves [25]. Awosika et al. [26] fertilized tomatoes using pig manure and NPK (15:15:15) and discovered that 187 kg/ha NPK plus 6 t/ha pig manure had the greatest results in terms of leaf number, plant height, fruit weight, yield, and quality. Prativa and Bhattarai [27] investigated the impact of integrated nutrient management on tomato plant growth, yield, and soil nutrient status (*Lycopersicon esculentum* L.). The study indicated that combining organic manures with inorganic fertilizers improved overall plant growth, yield, and soil macronutrient status more than either nutrient applied alone. Prakash et al. [28] investigated the influence of humic acid (HA) and SLF on the growth and nutritional quality of *Abelmoschus esculentus*. A combined impact of SLF and HA (8.5%: 0.5 %) was beneficial in enhancing the growth of the plant in the pots that is also reflected in the increased carbohydrate and protein content in *Abelmoschus esculentus*. Mukta et al. [29] found that using vermicompost as an organic fertilizer at a rate of 10 t/ha in conjunction with 50% chemical fertilizer resulted in the best tomato production and quality.

Current study was conducted to increase the growth, yield, and chemical content of tomato (*Lycopersicon Esculentum* L. Mill) treated with mixed fertilizers at different rates (5% SLF + PU50), (10% SLF + PU50), and (30% SLF + PU50), (50% SLF + PU50).

Materials and methods

Seaweed extract preparation (SLF). A fresh sample of seaweed (*Gracilaria manilaensis*) was collected from Pantai Merdeka, Sungai Petani, Kedah. To eliminate adhering material and sand particles, the seaweed was carefully washed with seawater immediately after collecting, followed by freshwater. Clean seaweed was sun-dried for 7 days in the open air before being oven-dried for 48 hours at 60°C and ground to a fine powder with a mixer grinder. The seaweed powder was then used to make seaweed liquid extract (SLE) using the methods described by Srijaya et al. [30], Ganapathy and Sivakumar [31], and Rathore et al. [32].

In a sealed conical flask, four liters of water were added to 1 kg of dried seaweed and heated for 45 minutes at 60°C. The content was filtered through four layers of muslin cloth after cooling. The filtrate collected (2.150 mL) was 100% seaweed liquid fertilizer (SLF), and different concentrations of SLF, namely 5, 10, 30, and 50%, were prepared using distilled water [33]. Using an atomic absorption spectrophotometer, physical observations such as colour, pH, and different components of macronutrients (calcium, magnesium, potassium, phosphorous, nitrogen) and micronutrients (iron, magnesium, zinc, copper, and nitrate) were calculated [34]. Table 1 shows the physicochemical properties of SLF of *Gracilaria manilaensis* before preparation of different concentrations.

Table 1 – The physicochemical analysis of *Gracilaria manilaensis* (SLF)

Parameters	Values
Colour	Brown
pH	6.74
Nitrogen	400 (mg/L)
Calcium	156.06 (mg/L)
Magnesium	110.09 (mg/L)
Sodium	291.04 (mg/L)
Potassium	180.3 (mg/L)
Iron	6.9 (mg/L)
Phosphate	43.06 (mg/L)
Chloride	2180.8 (mg/L)
Sulphate	58.7 (mg/L)
Zinc	1.1 (mg/L)
Copper	1.7 (mg/L)
Nitrate	127.09 (mg/L)

Synthesis of nitrogen fertilizer (PU). The nitrogen fertilizer (PU) based on polyvinyl alcohol (PVA) and urea (U) was synthesized in an aqueous solution using Lewis acid (acetic acid) as a catalyst. The following procedure was used to synthesize PVA/U blends with a constant ratio, i.e., 50:50. (PU50). In an Erlenmeyer flask, the PVA and U were dissolved in 300 mL of distilled water. The solution was stirred using a magnetic stirrer, and the flask was sealed with a septum stopper. The solution was then flushed with nitrogen gas before being administered through a hypodermic needle, and another needle was placed within the stopper for gas outflow. The solution was continually agitated using a magnetic stirrer, and the nitrogen gas was bubbled at 30 minutes intervals.

The appropriate amount of glacial acetic acid was injected into the solution until pH 4 was attained, and nitrogen gas flushing was maintained for another 30 minutes. The nitrogen gas bubbling was stopped, the needles were withdrawn from the stopper, and the flask was sealed with Teflon tape. The temperature of the reaction was kept constant at 90°C by immersing the flask in a constant-temperature oil bath. When the pH remained constant at 4, the process was stopped. The polymer solution was precipitated in an excess of methanol, and the product was dried in a vacuum at 35°C. The nitrogen fertilizer was prepared and analyzed using the methods described earlier by El-Sayed et al. [35] (^{1}H NMR, FTIR, SEM, DSC, and TGA). The elemental analysis was performed using a Vario Micro Elemental Analyzer (Elementar, Germany) to determine the carbon, nitrogen, and oxygen content of the fertilizers, as indicated in Table 2.

Table 2 – The elemental composition of nitrogen fertilizer (PU)

	Elements	C (%)	N (%)	O (%)
PU50	(PVA: U) (50:50) wt.%	28.79	34.09	37.58

Preparation of mixed fertilizer (SLF+PU50). Mixed fertilizers (SLF+PU50) were a 50/50 w/v mixture of SLF with concentrations ranging from 5, 10, 30, 50, and 50% nitrogen fertilizer PU50. Mixed fertilizers were used with a constant concentration of 1% w/v using distilled water.

Experimental design and treatment. The crop plant selected for the present study was *Lycopersicon esculentum* (tomato). The hybrid tomato seeds (Pearl-F_1) were purchased from the local market and kept for one hour in a glass beaker with fresh water. Only the seeds that sank at the bottom of the beaker were used in the experiment. The seeds were carefully sewn in plastic trays, and the compost soil was kept wet by spraying with water daily. After two weeks, the germinated seedlings were transferred and planted in plastic pots. The seedlings were planted 5 cm deep into the soil and the depression was then loosely covered back by the soil. The soil was air-dried, sieved, and packed (13.5 kg/pot), and was properly filled in 15 pots.

The day on which the seedlings were planted in the pot was treated as day zero (Figure 1). The plants were watered every day or on alternate days depending on the requirement.

All 3 sets were prepared in five replicates. Mixed fertilizer treatment was given to the plants namely (SLF+PU50) and a set of control plants. In each of the treatments, 500 mL (1% w/v) of SLF+PU50 was applied directly to the soil. The first treatment was given to 15-day-old seedlings. Thereafter, the treatments were given at intervals of 15 days each until 90 days. The control set was watered only with tap water without any fertilizers.

Physical and chemical properties of the soil. In this study, the soil's physical and chemical properties were analyzed before the addition of the mixed fertilizers in different concentrations to the experimental soil to know the type and properties of the soil. The results are presented in Table 3. The ingredients of the experimental soil were a mixture of clay (56.63%), fine sand (14.22%), and silt (24.15%). The chemical properties of the soil were 1.4 mhos/cm^3, 81.0 ppm N, 3.04 ppm P, 40.8 ppm K, 0.6 ppm of organic matter and pH was 7.8.

Figure 1 – Tomato plants after two weeks of germination

Table 3 – The physical and chemical properties of the soil

Physical properties	
Sand	56.63 (%)
Silt	24.15 (%)
Clay	14.22 (%)
Soil texture	Sandy loam
Chemical properties	
pH	7.8
Ec	1.4 (mhos/cm^3)
Available N	81.0 (ppm)
Available P	3.04 (ppm)
Available K	40.8 (ppm)
Organic matter	1.6 (%)

Data recorded. Vegetative growth. Plant height, number of major lateral branches, number of leaves, leaf area, and fresh and dry weights of shoots were measured at 4 and 8 weeks.

Chemical composition. Leaves disks were collected 4 and 8 weeks after transplanting to assess chlorophyll a, b according to the method described by Sartory and Grobbelaar [36]. Total carbohydrate content in dry matter of leaves was determined spectrophotometrically method described by Dubois et al. [37]. Nitrogen, phosphorus, and potassium elements were determined in the leaves of tomato plants via digestion procedure according to Piper [38]. Nitrogen content was determined by the modified micro-Kjeldahl method as described by Pregl [39]. Phosphorus and potassium contents in the sample were estimated using ammonium molybdate and flame photometer methods respectively, according to Chapman [40].

Flowering and fruit yield. The number of nodes bearing the first flower, the number of flower clusters per plant, the number of flowers per cluster, the number of flowers per plant, the weight, and the number of fruits per plant were all recorded.

Physical characteristics of fruits. The fruit shape index was calculated using the ratio of vertical to horizontal diameters. Fruit volume was determined by using the immersion method.

Chemical characteristics of fruits. The soluble solids content (SSC) was assessed using a hand refractometer and the AOAC technique [41]. The technique published by AOAC [42] was used to calculate titratable acidity. The ascorbic acid concentration (vitamin C) was tested following AOAC guidelines [43]. Lycopene in tomato samples was extracted using hexane: ethanol: acetone (2:1:1) (v/v) mixture according to Sharma and Le Maguer's technique [44].

Statistical analysis. The data calculated on various variables were subjected to analysis of variance (ANOVA) to identify differences between treatments and their interactions. The Least Significant

Difference (LSD at 5%) test was used to separate the means. The ANOVA and LSD were computed using the statistical computer program Statistix 8.1 [45].

Results and discussion

Plant height (cm). The findings shown in Figure 2 showed that the combination fertilizers (SLF + PU50) had a highly significant ($p < 0.05$) effect on plant height at 4 and 8 weeks. Plant height increased when SLF concentrations decreased from 50 to 10%. Plant height treated with 10% SLF + PU50 was substantially greater than control plants and other treatments at 4 and 8 weeks. Treatments with 10% SLF + PU50 mixed fertilizer performed best, followed by 30% SLF + PU50, 50% SLF + PU50, and 5% SLF + PU50. The increase in tomato plant height caused by combined fertilizer (SLF + PU50) might be attributed to hormone components such as cytokinins and auxins in SLF and nitrogen in PU50, which promote plant height.

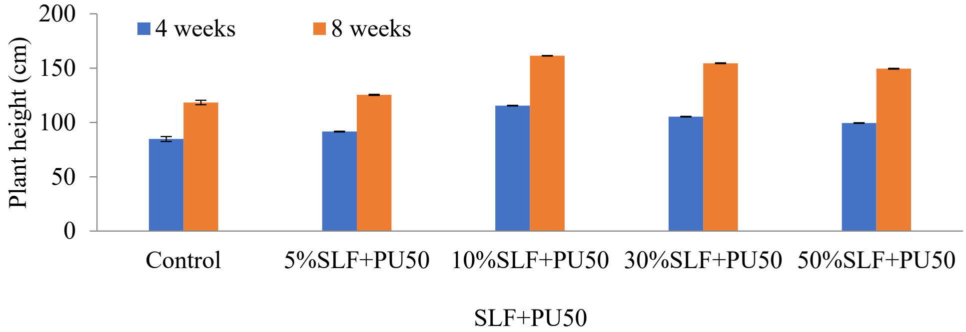

Figure 2 – Effect of mixed fertilizer on tomato plant height

Polyvinyl alcohol-urea blend (PU) has a cross-linked structure of hydrophilic urea. The presence of polyvinyl alcohol improves the ability to adsorb the metals from soil and seaweed. This, in turn, improves the soil's water-holding capacity, regains its fertility, and in sustainable manner for improved plant growth [13,46-48]. Similar results were reported by Wakifatul et al. [49] on soybeans and Cheng et al. [50] on lettuce, who found that fertilizer treatment, i.e., a blend of SLF and organic fertilizer, increased plant height.

Number of lateral branches. The effect of mixed fertilizer (SLF + PU50) on lateral branch numbers per tomato plant is shown in Figure 3. The treatment (10% SLF + PU50) resulted in a substantial increase in lateral branch numbers per tomato plant at the 5% level of probability when compared to the mixed fertilizers (30% SLF + PU50), (50% SLF + PU50), and control plants. At 4 and 8 weeks, the plants treated with mixed fertilizer (10% SLF + PU50) had the most lateral branches compared to the other treatments. The 10% SLF + PU50 treatment increased lateral branch numbers by 61.7 and 79.6% at 4 and 8 weeks, respectively, compared to the control, which was expected due to the positive effect of mixed 10% SLF with PU50 (N: 34.1%) on soil edifice environmental conditions, which affected tomato plant vegetative growth [51]. These findings were consistent with those reported by Sridhar and Rengasamy [52-54] on *Tagetes erecta* and chili, who discovered that the best two interaction treatments for increasing lateral branch number per plant were 10% SLF combined with 50% recommended rate of chemical fertilizer. The plants treated with 5% SLF + PU50 at 4 and 8 weeks produced the fewest lateral branches.

Number of leaves per plant. Figure 4 shows that the application of mixed fertilizer (SLF + PU50) at 8 weeks induced a substantial increase in the number of leaves per plant at the 5% probability level when compared to the treatment of mixed fertilizer at 4 weeks. The treatment with 10% SLF + PU50 produced the most leaves per plant (78.5 and 125.6) at 4 and 8 weeks, respectively, while the treatment with 5% SLF + PU50 produced the fewest leaves per plant (35.4 and 74.5) at 4 and 8 weeks, respectively. This is due to the continuous release of nutrients from SLF as well as nitrogen from PU50. The increase in leaves number following mixed fertilizer (10% SLF + PU50) treatments proved the effect of mixed fertilizer in enhancing soil physical qualities and promoting vegetative growth in leafy vegetables [55-57]. Dawa et al. [24, 25] discovered that foliar application of seaweed extract with chicken manure as a source of organic fertilizer and in the presence of biofertilizers increased vegetative plant development and N, P, and K percentages in leaves on pepper and tomato plants. According to Khan et al. [58], combining N with organic fertilizer resulted in higher plant height and number of leaves of pepper plants than using organic or biofertilizers alone.

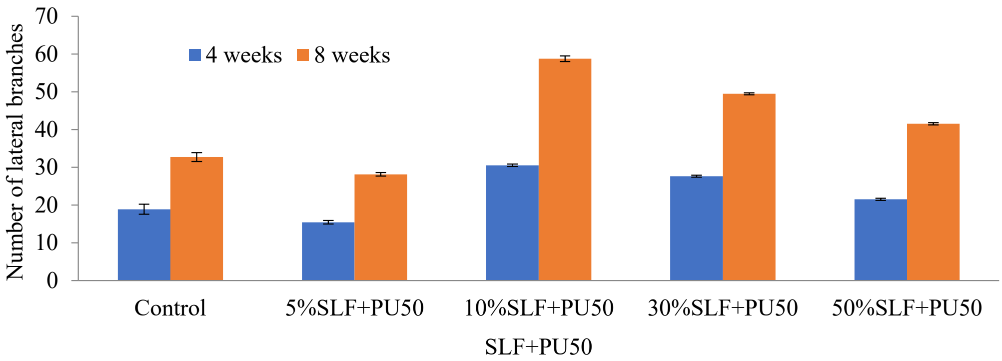

Figure 3 – Effect of mixed fertilizer on the number of lateral branches per tomato plant

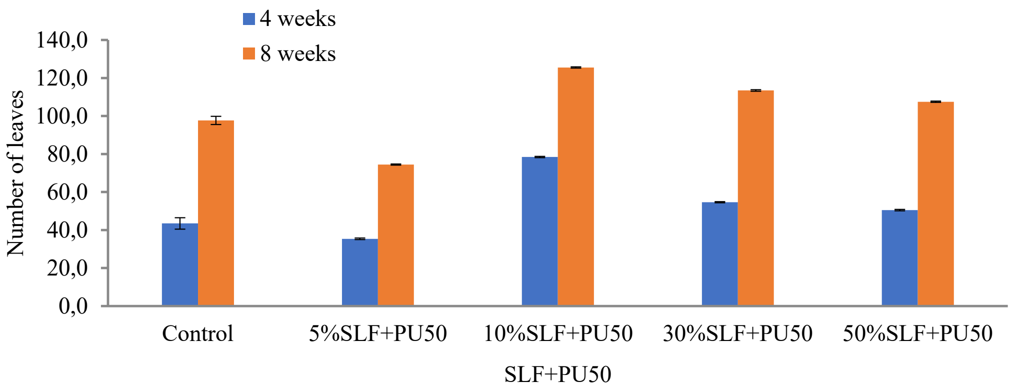

Figure 4 – Effect of mixed fertilizer on the number of leaves per tomato plant

Leaf area (cm^2). Figure 5 depicts the effect of a mixed fertilizer (SLF + PU50) on leaf area after 4 and 8 weeks of growth. When compared to control plants, the usage of mixed fertilizer resulted in substantial increases ($p < 0.05$) in leaf area. The tomato plants' leaf area rose when the SLF content in the mixed fertilizer was reduced from 50 to 10%. Plants fertilized with 10% SLF + PU50 had the largest leaf areas, with 265.9 and 291.275 cm^2, respectively, whereas plants fed with 50% SLF + PU50 had the smallest leaf areas. At 4 and 8 weeks, SLF + PU50 had leaf areas of 231.0 and 256.15 cm^2, respectively.

Mixed fertilizer (10% SLF + PU50) can be given to tomato plants to improve the nutritional content of the soil and, as a result, increase the vegetative growth of tomato plants. The leaf area measurement on the control plants was the smallest. These findings agreed with those of Ogundare et al. [59], Dawa et al. [24], and Sridhar and Rengasamy [54], who found that combining SLF with chemical fertilizer enhanced leaf area in tomato plants and chili plants, respectively. Several studies found that combining low-level N fertilizer or NPK with biofertilizer improved citrus plant leaf area more than using high-level N fertilizer or NPK in a single application or coupled with biofertilizer [60,61].

The fresh and dry weight of shoots (g/ plant). Figure 6 shows that the combined fertilizer (10% SLF + PU50) induced a substantial increase in the fresh and dry weight of shoots at the 5% probability level when compared to the control plants and other treatments. This might be because seaweed contains growth-promoting substances, as well as nitrogen in PU50 fertilizer. Nitrogen is essential for plant growth because it promotes protein synthesis, amino acid synthesis, enzyme, and chlorophyll formation, which affects cell division, the number of leaves and branches per plant, and dry matter accumulation [24, 49, 62].

The increased percentages of fresh weight of shoots over non-fertilized treatments ranged from 14.7 to 34.4 % at 4 weeks and from 88.3 to 160.1% at 8 weeks, with decreasing concentrations of SLF in the mixed fertilizers ranging from 50 to 10%.

The mixed fertilizer 5% SLF+PU50 had no significant effect on the fresh and dry weights of the shoots. The treatment of 10% SLF + PU50 at 8 weeks led to the greatest percentage values of fresh and dry weights of tomato shoots (160.1 and 159.4%, respectively).

Chlorophyll (a, b) content (mg/ dm²). The contents of chlorophyll a and b in tomato leaves were influenced by mixed fertilizer (SLF + PU50) (Figure 7). The treatment (SLF + PU50) resulted in a substantial increase ($p< 0.05$) in leaf chlorophyll a and b contents compared to control plants at 4 and 8 weeks. Plants fertilized with 10% SLF + PU50, on the other hand, had the highest chlorophyll (a, b) concentrations in leaves, followed by plants fertilized with 30% SLF/PU50, 50% SLF + PU50, and 5% SLF + PU50 at 4 and 8 weeks. The increase in chlorophyll content is caused by cytokines found in seaweed extract and nitrogen found in PU fertilizers, both of which drive physiological activities and increase chlorophyll in plants [63, 64].

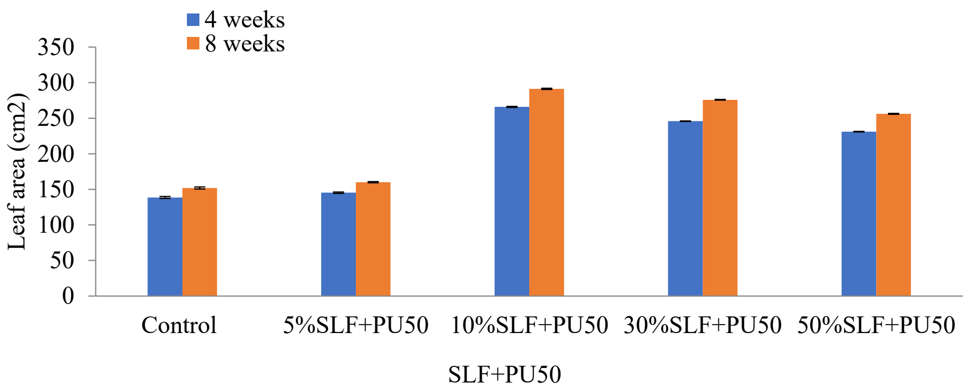

Figure 5 – Effect of mixed fertilizer on the tomato leaf area

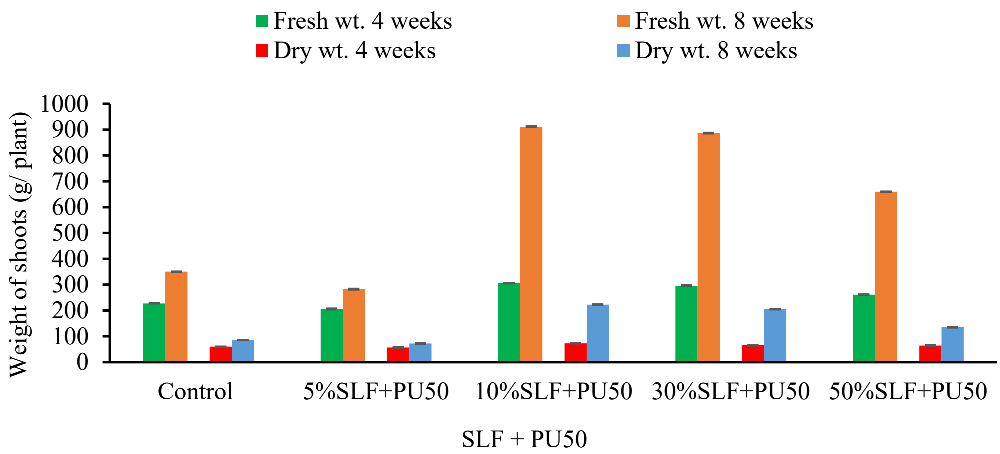

Figure 6 – Effect of mixed fertilizer on shoot fresh and dry weights per tomato plant

These findings were consistent with those reported by Sridhar and Rengasamy [54], Zeid [65], Samane et al. [66], and El-Tantawy [67], who investigated the effect of mixed fertilizers (10% SLF of S. *wightii* + 50% chemical fertilizer including urea, superphosphate, and potash), and spraying of chitosan and aminofort on the photosynthetic pigments in *A. hypogea, C. annum* (Chilli) and tomato leaves, respectively. The results revealed that the highest concentration of photosynthetic pigments was achieved by the interaction between seaweed extract liquid and nitrogen fertilizers.

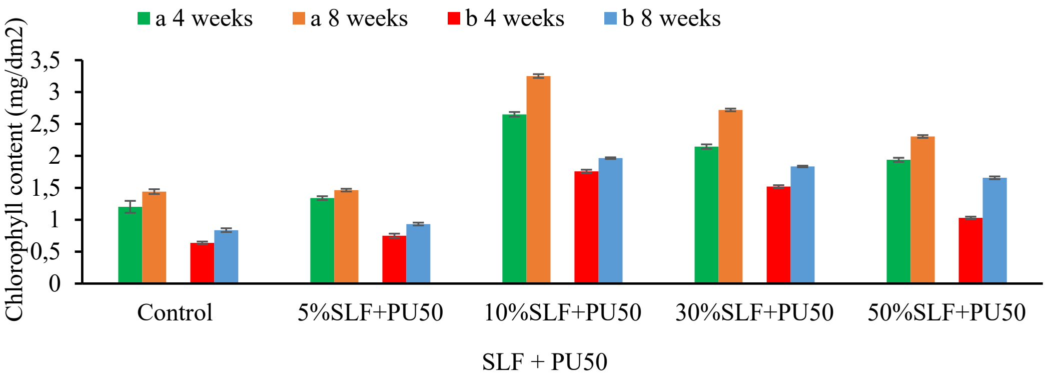

Figure 7 – Effect of mixed fertilizer on chlorophylls a and b in leaves of tomato plants

Carbohydrate content (%). Figure 8 shows the effect of different mixed concentrations of SLF with PU50 (N: 34.1%) on total carbohydrate content in tomato plant leaves. The results revealed that the combined fertilizers (SLF + PU50) induced a significant increment ($p < 0.05$) in leaf carbohydrate content when compared to the control plants. This is due to enhanced nitrogen photosynthetic activity and carbohydrate production and accumulation. Furthermore, the interaction between seaweed and chemical fertilizer played an important role in improving plant growth through the biosynthesis of endogenous hormones of seaweed which are responsible for promoting plant growth [54]. The highest value of total leaf carbohydrate content (17.75%) was detected in tomato plants fertilized with 10% SLF + PU50, whereas the lowest leaf carbohydrate content (12.3%) was obtained from plants fertilized with mixed fertilizer (5% SLF + PU50) at 8 weeks. Therefore, it could be concluded that the combined effect of 10% SLF with PU50 has met the required micronutrients in tomato plants than 30 and 50% SLF combined with PU50. With the use of PU and SLF, nutrients are released at a slower rate throughout the seasons, and plants are able to take up most of the nutrients without waste by leaching. This result following with the study of Nayan et al., [68], who found that polyvinyl alcohol (PVA) blended with starch and chitosan to release the nutrients directly to the root of the plants, decrease the nitrogen loss and reduce water and soil pollution.

Nitrogen, phosphorus, and potassium content (%). Figure 9 shows the effect of combined fertilizers (SLF + PU50) at varying concentrations of SLF on nutrient content in tomato plant leaves. When compared to control plants, mixed fertilizers caused significant increments ($p < 0.05$) in leaf nitrogen, phosphorus, and potassium percentages. However, higher nitrogen (5.8%), phosphorus (0.78%) and potassium (3.18%) contents were recorded by tomato plants fertilized with 10% SLF + PU50, while lower nitrogen (3.5%), phosphorus (0.45%), and potassium (2.17%) contents were recorded by tomato plants fertilized with 5% SLF + PU50 at 8 weeks as compared to control plants (3.29%, 0.41% and 1.94% respectively) at 8 weeks.

The purpose of combining PU and SLF is to speed up the uptake of nutrients from the soil and SLF, resulting in higher nutrient percentages in plant leaves. These results are supported by Mikkelsen [69, 70]. The presence of marine bioactive substances in seaweed extract and nitrogen in PU enhances stomata uptake efficiency in treated plants compared to non-treated plants [71, 72]. According to Paul and Mannan [73], Asadu and Unagwu [74], Dawa et al. [24], and Sridhar and Rengasamy [54], the nutrient percentages in tomato leaves were influenced by the mixture of different fertilizer compounds such as organic, inorganic, chemical, and seaweed.

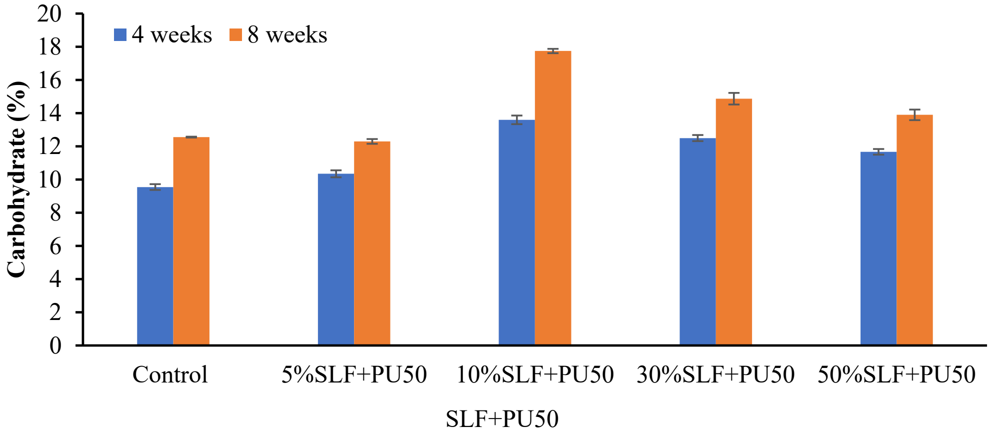

Figure 8 – Effect of mixed fertilizer on carbohydrate in leaves of tomato plant

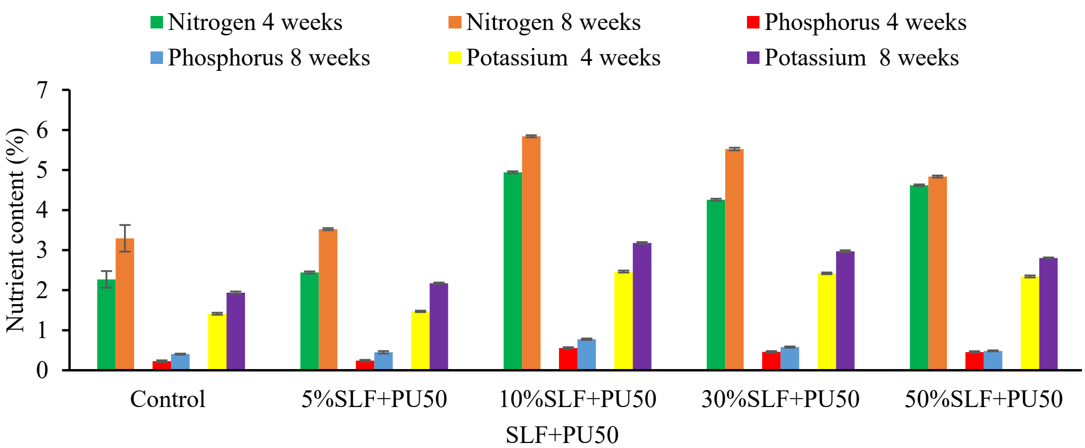

Figure 9 – Effect of mixed fertilizer on nitrogen, phosphorus, and potassium percentages in leaves of tomato plants

Characteristics of flowers. The results in Figures 10 and 11 showed that the mixed fertilizers (SLF + PU50) caused significant increment ($p < 0.05$) in the node number bearing the first flower, the number of flower clusters per plant, and the number of flowers per cluster, compared to the control plants.

An increased in the concentration of SLF in mixed fertilizer (SLF + PU50) from 5 to 10% resulted in increased node number bearing from 6.07 to 9.83, the number of flower clusters per plant from 15.30 to 33.44, the number of flowers per cluster from 4.40 to 9.13 (Figure 10) and the number of flowers per plant from 65.28 to 105.63 (Figure 11).

The concentration of SLF in mixed fertilizer (SLF + PU50) was increased from 10 to 50%, which resulted in a reduction in the above flowering characters. Tomato plants fertilized with 10% SLF + PU50 produced more flower characteristics than those treated with 30% SLF + PU50, 50% SLF + PU50, 5% SLF + PU50, and control. This might be attributed to the presence of plant growth regulating substances and hormones in seaweed, as well as nitrogen in PU, which may encourage flowering by initiating robust plant growth.

The findings were consistent with those of Najaf et al. [75] and Ilupeju et al. [76], who detected a highly significant increase in the number of flowers on tomato plants treated with nitrogen fertilizer and two types of biofertilizers. Wakifatul et al. [49] reported that the interaction of seaweed with cattle urine enhanced the flower characters of soybean plants. Sridhar and Rengasamy [52,53] observed a similar behavior while studying the interaction of SLF with chemical fertilizer on the flowers of *Tagestes erecta*.

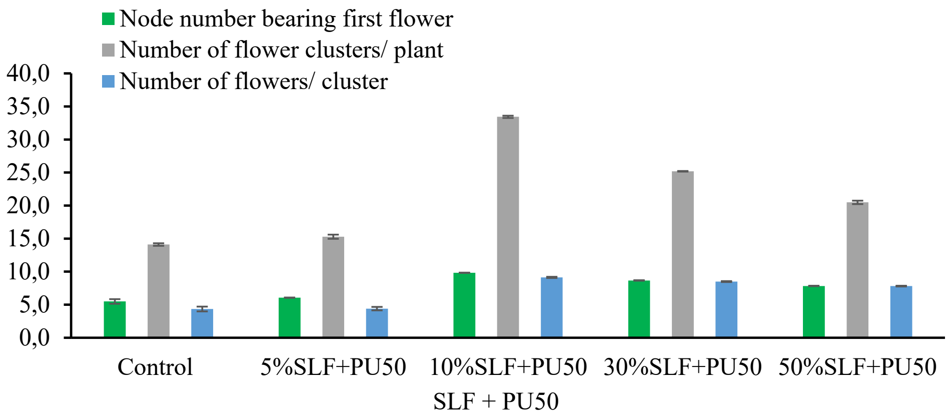

Figure 10 – Effect of mixed fertilizer on node number bearing first flower, number of flower clusters per plant and number of flowers per cluster

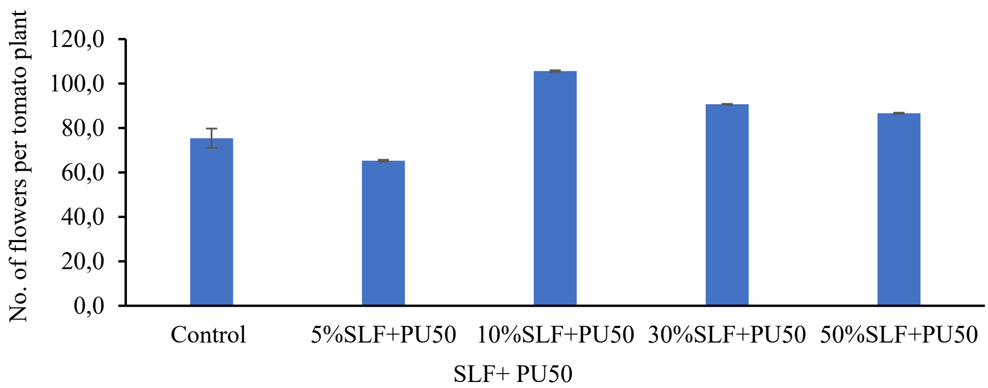

Figure 11 – Effect of mixed fertilizer on the number of flowers per tomato plant

Number of fruits per plant. The results in Figure 12 showed the mixed fertilizer (SLF + PU50) at a concentration of 10% SLF caused a significant increment at 5% probability level in the number of fruits per plant, compared to other treatment and the control plants. The highest number of fruits per plant (37.48) was present in the (10% SLF + PU50) treatment, while the lowest number of fruits per plant (26.25) was observed in (50% SLF + PU50), compared to the control plants (24.25). The increased number of fruits per plant might be due to the presence of some growth-promoting substances in SLF and nitrogen in PU. This might have helped in producing a higher amount of carbohydrates, which might have translocated from source (leaf) to reproductive parts (sink), resulting in a greater number of fruits [77-79]. This result is similar to Juárez-Maldonado et al. [80] and Pinedo et al. [12], who found an increase in the number of tomato fruits treated with copper encapsulated in chitosan-polyvinyl alcohol. The same behaviour was reported by Ogundare et al. [59] and Libert et al. [81] when they studied the influence of the interaction between organic and inorganic fertilizers on tomato fruit yield.

Weight and volume of fruits. Figures 13-15 showed that the combination fertilizer (SLF + PU50) at a concentration of 10% SLF caused a significant increment at a 5% probability level in the fruit weight, fruit volume and shape index of fruit compared to all other treatments and the control plants. The application 10% SLF + PU50 increased fruit weight (154.9%) (Figure 13), fruit volume (42.7%) (Figure 14) and shape index of fruit (31.8%) (Figure 15), while application 5% SLF + PU50 increased fruit weight (21.6%) and fruit volume (4.2%), compared to the control plants.

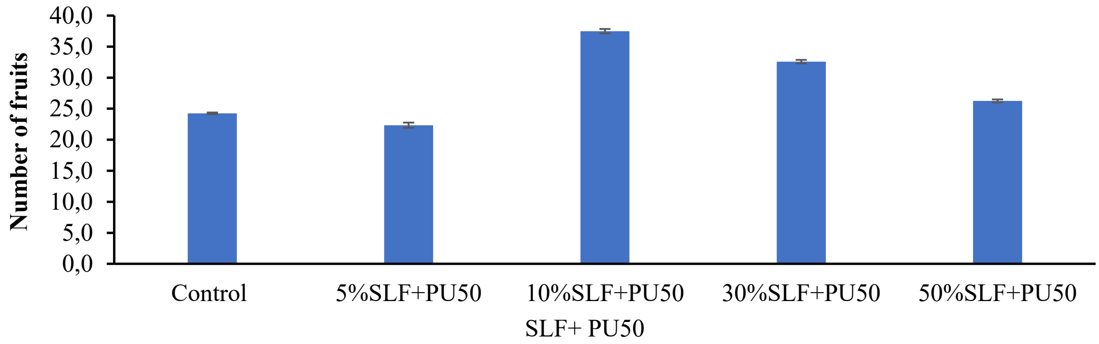

Figure 12 – Effect of mixed fertilizer on the number of fruits per tomato plant

The enhanced weight, volume, and shape index of fruit over the control were attributed to the interaction fertilizer (SLF + PU50) providing the micronutrients to the plants in an optimal range. Similar findings were reported by Dimitrios et al. [82], Chanda et al. [83], Najaf et al. [75], Salama et al. [84], IIupeju et al. [76], and Ogundare et al. [59], who found that the application of mixed fertilizers (cow manure + NPK) resulted in the highest tomato fruit growth, which could be interpreted as the release of nutrients from organic and inorganic fertilizers at different times.

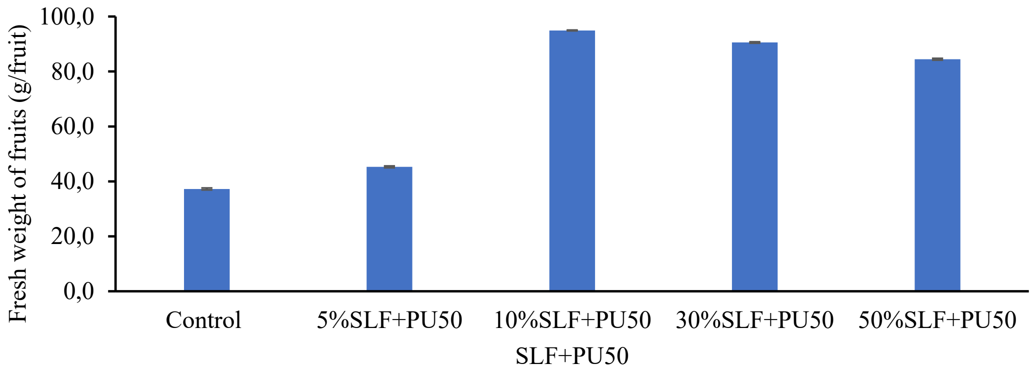

Figure 13 – Effect of mixed fertilizer on the fresh weight of tomato fruits

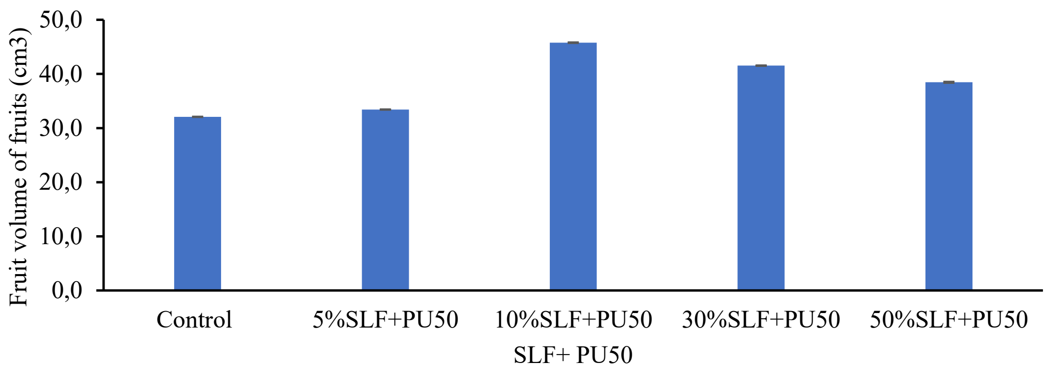

Figure 14 – Effect of mixed fertilizer on the volume of tomato fruits

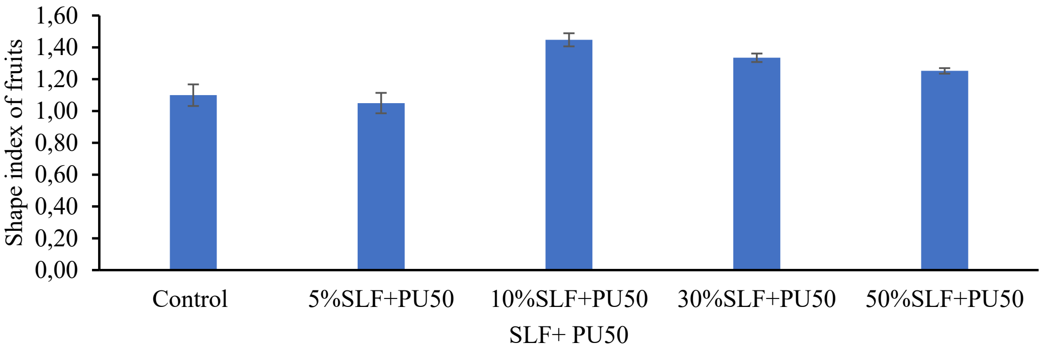

Figure 15 – Effect of mixed fertilizer on the shape index of tomato fruits

Chemical content of fruits. The results in Figures 16 and 17 demonstrated that the mixed fertilizer (SLF + PU50) at a concentration of 10% SLF caused a considerable increase in soluble solids content (SSC), acidity, vitamin C, and lycopene pigment in tomato fruits when compared to other treatments and control plants. Soluble solid concentration (3.72%) was lower in tomato fruits treated with mixed fertilizer (5% SLF + PU50). While tomato fruits treated with (10% SLF + PU50) had a greater SSC (6.32%) than control plants (3.60%) (Figure 16).

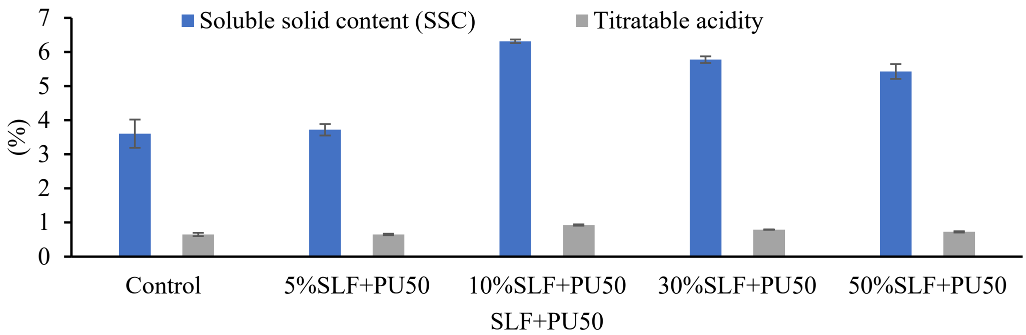

Figure 16 – Effect of mixed fertilizer on SSC and titratable acidity in tomato fruits

IIupeju et al. [76] obtained greater total soluble solids with 100% recommended doses of mixed fertilizers and biofertilizers. When compared to the control plants, the 10% SLF + PU50 treatment had the highest titratable acid content (0.93%) in the tomato fruits, while the 5% SLF + PU50 treatment had the lowest titratable acid percentage (0.65). Hasanein et al. [85] found a similar effect of biofertilizers and amino acids on tomato fruits. The results can be explained by nutrient availability to the plants and their balanced supply from mixed fertilizers SLF and PU50 in the required amounts during fruit formation.

Figure 17 shows that the ascorbic acid content (23.78) and lycopene (41.75) in tomato fruits treated with mixed fertilizers (10% SLF + PU50) were higher than in other treatments and control plants. Fruits produced by plants treated with 5% SLF + PU50 and control had lower percentages.

This was consistent with the findings of Peyvast et al. [86], who discovered that mixed fertilizers (nitrogen and potassium) boosted ascorbic acid levels in tomato fruits. These findings confirm that the mixed fertilizer (10% SLF + PU50) has a positive effect on soluble solids content (SSC), acidity, vitamin C, and lycopene levels in tomato fruits. A similar finding was reported by IIupeju et al. [76] and Makinde et al. [87] when they investigated the effects of organic and inorganic fertilizer interactions on the growth, fruit production, nutritional, and lycopene content of three tomato varieties [88, 89].

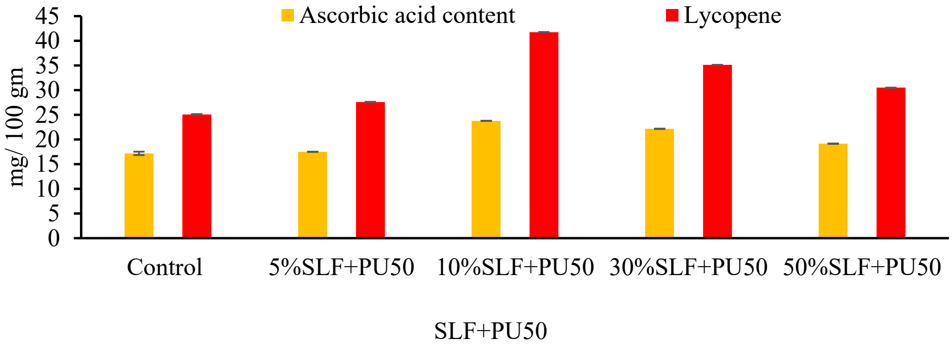

Figure 17 – Effect of mixed fertilizer on ascorbic acid and lycopene in tomato fruits

Conclusion

These experiments aimed to investigate the effect of mixed fertilizer (SLF + PU50) on the growth, yield, and chemical composition of tomato plants (*L. esculentum* Mill). To achieve the goal of this study, the experiment was designed in a randomized complete block design (RCBD) with each treatment replicated five times. The basic properties of the experimental soil have been tested. Soil pH, EC, available N, P and K were 7.8, 1.4 mhos/cm^3, 81.0 ppm, 3.04 ppm and 40.8 ppm, respectively. Treatments included: control (without fertilizers), four mixed fertilizer concentrations (SLF + PU50) (5% SLF + PU50, 10SLF + PU50, 30SLF + PU50 and 50% SLF + PU50). The data were analyzed using variance analysis (ANOVA) and compared using fertilizer-free control. Mixed fertilizer-treated tomato plants (10% SLF + PU50) showed maximum growth and control between the various experimental concentrations. Tomato plants fertilized with 10% SLF + PU50 produced the highest vegetative growth, flower, and fruit characteristics. Tomato fruit yields (54.5%) were best applied with mixed fertilizers (SLF + PU50) at 10% SLF + PU50. It may be recommended to use 10% SLF mixed with PU50 to obtain high vegetative growth and yield tomato fruits.

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