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Effects of blended polyvinyl alcohol/urea on the growth, yield and chemical content of tomato (*Lycopersicon esculentum* L. Mill)

Abstract. Tomato (*Lycopersicon esculentum* L. Mill) is one of the most important solanaceous vegetables widely cultivated in the world. The growth yield and chemical content of tomato (*Lycopersicon esculentum* L. Mill) treated with nitrogen fertilizers (PU) were investigated. Nitrogen fertilizers were based on polyvinyl alcohol blended with three different composites of urea (PU35, N: 8.45%; PU50, N: 34.1%, and PU65, 44.04%). In each of the five replicates of the treatments, 500 mL (1% w/v) of PU was applied directly to the soil. The first treatment was given at 15-day-old seedlings. Thereafter, treatments were given at intervals of 15 days (6 times) each until 90 days. Final harvest was at 112 days. Data was analyzed using variance analysis (ANOVA) and compared using control without fertilizer. The vegetative growth, leaf and fruit chemical composition, and flowering and fruiting of tomato responded positively to PU fertilizers compared to control plants. However, application of PU50 (nitrogen content 34.1%) gave significant increase in vegetative growth, chlorophylls a and b, flower and fruit characteristics more than PU35, PU65 and control.
Key words: Nitrogen fertilizers, tomato, growth, yield, parameters.

Introduction

Tomato (*Lycopersicon esculentum* Miller) belongs to the family *Solanaceae* and is an important vegetable crop grown throughout the world under field and greenhouse conditions [1-5]. Growing tomato is difficult due to many constraints (diseases, climate, nutrition, etc.), while the fruit itself has to meet certain market requirements. Numerous authors have studied the effects of different plant nutrients on the yield and quality of tomato and it becomes clear that some of these nutrients play key role in tomato production [2-8]. Nitrogen is one of the most important elements for plant growth, development and nutrition. Among commonly used are ammonium-, nitrate-, amide- and cyanamide-nitrogen fertilizers [6]. A number of researchers have studied the effects of nitrogen fertilizers on growth and yield components of tomato plants [7-11]. They reported that nitrogen application showed an increase in stem length, number of flowering branches and total plant dry weight. The amount of nitrogen required for optimal growth is between 2-5 % of plant dry weight. A higher supply of nitrogen has side effects such as delayed senescence, change in plant morphology, i.e., smaller roots and higher shoot/root dry weight ratio. Therefore, management of nitrogen fertilizers such as rate, type and application time are very important [12,13]. Asit et al. [5] reported that urea fertilization at the rate of 1,000 ppm increased tomato plant height (136.2 cm), number of leaves (30.73), number of green fruits per plant at harvest (21.08), number of flower clusters (11.89), number of flowers (75.18), fruit clusters (5.81), fruits per cluster (4.14), fruits per plant (21.49), and fruit length (4.72 cm), fruit diameter (6.58 cm) and weight of individual fruit (151.0 g). Mercado et al. [14] evaluated the impact of different concentrations of nitrogen on tomato seedling production. The nitrogen fertilizer was based on $N\text{-}NO^{3-}$ with different concentrations of 4, 8, 12 and 16 mEq/L with highest morphological values at 16 mEq/L and shortened production time of seedlings for transplant. Nitrogen had the largest effect on yield and quality of tomato [15]. Number of authors reported that increased concentration of nitrogen fertilizer led to increase in nitrogen content in plant leaves [16,17]. Increase of nitrogen content results in increased protein concentration and consecutive increase in plants vegetative growth [18]. When urea fertilizer inputs to the soil system exceed the crop needs, there is a possibility that half of the applied fertilizer escapes to the environment due to leaching, surface runoff, decomposition and ammonium volatilization in the soil as only a fraction is actually absorbed by plants. The objective of this study was to investigate nitrogen fertilizers based on polyvinyl alcohol blended with different concentrations of urea on vegetative growth, yield and quality of tomato plants. With the use of PVA/U systems, 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.

Materials and methods

Synthesis of nitrogen fertilizers. The nitrogen fertilizers based on polyvinyl alcohol (PVA) with urea (U) were synthesized with composition ratios of 65: 35 (PU35), 50: 50 (PU50) and 35: 65 (PU65) respectively by blending polymerization in presence of acetic acid as catalyst. The preparation of nitrogen fertilizers and methods of analysis (^{1}H NMR, FTIR, SEM, DSC and TGA) have been described in a previous investigation [19]. The elemental analysis was carried out for the determination of carbon, nitrogen and oxygen content in the fertilizers as shown in Table 1.

Table 1 – Elemental composition of nitrogen fertilizer

Elements	C (%)	N (%)	O (%)
PU35	49.41	8.45	42.15
PU50	28.79	34.09	37.58
PU65	21.54	44.04	34.42

The analysis was performed on a Vario Micro Elemental Analyzer (Elementar, Germany). The chemical structure of PU is presented on Figure 1.

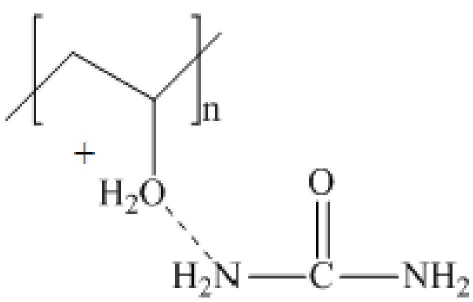

Figure 1 – Nitrogen fertilizer [polyvinyl alcohol + urea (PU)]

Nitrogen fertilizers (PU) were used in a constant concentration of 1% w/v using dH_2O.

Experimental design and treatments. The crop plant selected for the present study was *Lycopersicon esculentum* (tomato). The hybrid tomato seeds (Pearl – F1) were purchased from the local market and kept for one hour in a glass beaker with fresh water. Only the seeds that settled at the bottom of the beaker were used for the experiment. Seeds were carefully sowed in plastic trays and regular sprinkling with water was performed to keep the compost soil moist. After two weeks, germinated seedlings were transferred and planted in plastic pots. The seedlings were pushed 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.

Each pot was labelled with the pot number and the date of sowing of the seeds were recorded to determine the offset date for analysis. The day on which the seedlings were planted in the pot was treated as day zero. The plants were watered every day or on alternate days depending on the requirement.

All 3 sets were prepared in five replicates, with nitrogen fertilizer treatment given to the plants namely PU and a set of control pants. In each of the treatment, 500 mL (1% w/v) of PU was applied directly to the soil. The first treatment was given at 15-day-old seedlings. Thereafter, 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 order to know the type and properties of soil used for the experiment, its physical and chemical properties were analyzed prior to addition of the nitrogen fertilizer (PU). Results are presented in Table 2. 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.

Data recorded on vegetative growth. Plant height, number of main lateral branches, number of leaves, leaf area as well as fresh and dry weights of shoots were recorded at 4- and 8-weeks after transplanting.

Study of chemical composition. Leaf disks were taken at 4- and 8-weeks after transplanting to determine chlorophyll a, b according to the method described by Sartory and Grobbelaar [20]. Total carbohydrate content in dry matter of leaves was determined ин spectrophotometrically method described by Dubois et al. [21]. Nitrogen, phosphorus and potassium elements were determined in the leaves of tomato plants via digestion procedure according to Piper [22]. Nitrogen content was determined by modified micro-Kjeldahl method as described by Pregl [23]. Phosphorus content in the sample was estimated using ammonium molybdate method according to Chapman and Pratt [24]. Potassium was determined using flame photometer according to reference [24].

Table 2 – Physical and chemical properties of the soil.

Physical properties (percentage of mixed type of soil)	
Sand (%)	14.22
Silt (%)	24.15
Clay (%)	56.63
Soil texture	Clay **loam**
Chemical properties	
pH	7.8
Ec (mhos/cm^3)	1.4
Available N (ppm)	81.0
Available P (ppm)	3.04
Available K (ppm)	40.8
Organic matter (%)	0.6

Study of flowering and fruit yield. Node number bearing the first flower, number of flower clusters per plant, number of flowers per cluster, number of flowers per plant, weight and number of fruits per plant were recorded.

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

Study of chemical characteristics of fruits. Soluble solids content (SSC) was determined by hand refractometer according to the method described by AOAC, 1965 [25]. Titratable acidity was determined using the method described by AOAC, 2005 [26] and AOAC, 1970 [27]. Ascorbic acid content (vitamin C) was determined as described by AOAC, 1970 [27]. Lycopene in the tomato samples was extracted with hexane: ethanol: acetone (2:1:1) (v/v) mixture following the method of Sharma and Le Maquer [28].

Statistical analysis. The data calculated on different variables were subjected to analysis of variance (ANOVA) to observe the differences among the treatments and their interactions. Means were separated using Least Significant Difference (LSD at 5%) test. Statistical computer software Statistix 8.1 was used for computing the ANOVA and LSD [29,30].

Results and discussion

Plant height (cm). The plant height (cm) of the tomatoes treated with different nitrogen levels at 4 and 8 weeks is presented in Figure 2. As a result of the increased nitrogen rate up to PU50 (N: 34.1 %), the plant height of tomatoes is increased compared to other treatments. The plants fertilized with PU35 (N: 8.45 %) gave the tallest plant at 4 weeks (93.125 cm), while PU50 (N: 34.1 %) gave the tallest plant at 8 weeks (129 cm) compared with control (84.5 and 118.33 cm respectively). The highest N-rate of PU65 (N: 44.04 %) caused a decrease in plant height in comparison with PU35 (N: 8.45 %) lowest N-rate. The increase in plant height with N-fertilizer is attributed to the fact that nitrogen promoted plant growth which resulted in the progressive increase in plant height [31; 32]. Some investigators reported that nitrogen fertilizers including urea (46% N), ammonium sulphate nitrate (26% N), ammonium sulphate (21% N) increased plant height [31-34].

Number of lateral branches. Figure 3 shows maximum number of lateral branches per tomato plant fertilized with PU35 (N: 8.5%) at 4 and 8 weeks. PU50 (N: 34.1 %) and PU65 (N: 44.04 %) showed lower number of lateral branches per plant than PU35 and control at 4 and 8 weeks. Increases in nitrogen level within limit are associated with increase in number of lateral branches per plant [35-37]. The same behavior was reported by authors [33] when they studied synthetic polymer and nitrogen fertilizer on tomato plants. These results were also in harmony with those reported by authors [38] on mandarin. The researchers indicated that using mineral nitrogen fertilizer increased number of lateral branches per plant.

Number of leaves per plant. Increases in plant height resulted in an increase in the leaf number per plant as shown in Figure 4. Plants fertilized with PU35 (N: 8.5 %) resulted in the highest number of leaves per plant (51.5, 108.5), while the lowest number of leaves per plant was related to plant treated with PU65 (N: 40.3 %) 41 & 90.35 in the 4- and 8-weeks respectively. This is attributed to the response of tomato plants growth to nitrogen fertilizer (PU) and contributed to producing new shoot and increasing the number of leaves per plant [39]. Authors reported that number of leaves per tomato plant increased with increasing nitrogen rate in fertilizer [31, 40].

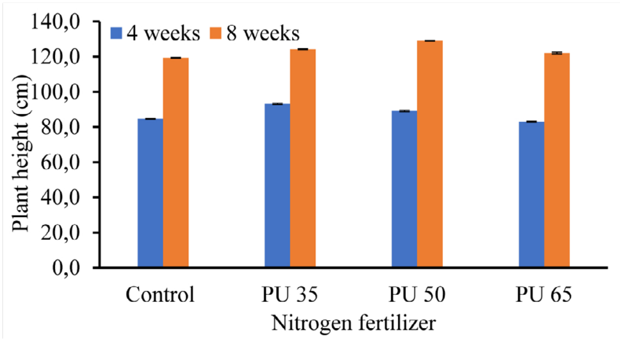

Figure 2 – Effect of nitrogen fertilizer on plant height of tomato

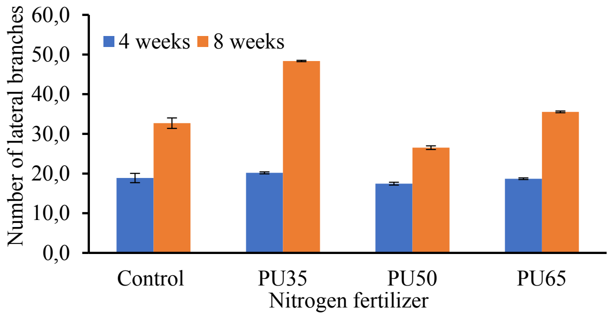

Figure 3 – Effect of nitrogen fertilizer on the number of lateral branches per tomato plant.

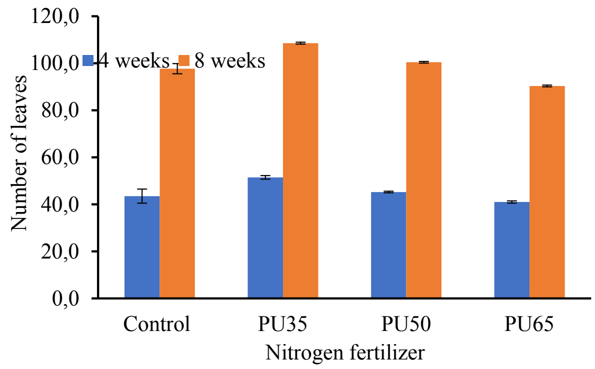

Figure 4 – Effect of nitrogen fertilizer on the number of leaves per plant tomato

Leaf area (cm^2). Figure 5 shows leaf area of tomato plants fertilized with different nitrogen levels (PU) compared with control (without fertilizers) at 4 and 8 weeks. When the levels of nitrogen are increased from 8.5 % (PU35) to 34.1 % (PU50), the leaf area of the tomato plants increased from 215.3 cm^2 to 248.2 cm^2 respectively at 4 weeks, and from 227.2 cm^2 to 265.5 cm^2 respectively at 8 weeks, due to the increase of photosynthetic activities of the leaf, which is directly responsible to increment leaf area of the plant [41]. At PU65 (N: 44.04 %) the leaf area reduced but was higher than the control. This effect of nitrogen on increasing leaf area of tomato plants was also observed by authors [42-44].

Fresh and dry weight of shoots (g/ plant). Figure 6 shows that the highest fresh and dry weights of tomato shoots were recorded by plants fertilized with PU50 (N: 34.1 %) at 4 and 8 weeks. On the other hand, tomato plants fertilized with PU65 (N: 44.04 %) exhibited the lowest fresh and dry weights of shoots but still higher than the control plants (without treatment). It was evident that PU fertilizer treatment caused an increase in the fresh and dry weights of shoots, especially PU50. The increase in fresh and dry weight of shoots attributed to the fact that nitrogen promotes plant growth [45]. The same behavior was reported by authors [46,47] when he studied the effect of different levels of urea on the growth and yield of tomato. The results showed that tomato plants fertilized with urea 150 mg per kg of soil gave the highest fresh and dry weights in comparison with plants fertilized with urea 200 mg per kg of soil.

Chlorophyll (a, b) content (mg/ dm^2). The role of nitrogen as a macronutrient essential for plant growth and development is well known. Nitrogen is the component of protoplasmic proteins, enzymes, amino acids, nucleic proteins and chlorophyll. Therefore, plant growth vigor is greatly affected by increasing or decreasing level of nitrogen application. The effect of nitrogen fertilizer (PU) with different levels of nitrogen on chlorophyll (a and b) contents in the tomato leaves at 4 and 8 weeks is shown in Figure 7. Generally, all N-fertilizer treatments caused an increase in the chlorophylls a and b content of the leaves as compared to the control. The highest content of the photosynthetic pigments was obtained from tomato plants fertilized with PU50 (N: 34.1 %) at 4 and 8 weeks. This favourable effect of N-application on plant growth might be due to the vital role of nitrogen on the synthesis of plant proteins, chlorophyll and enzymes. This result was in agreement with authors [46, 47] on tomato. If nitrogen was added at high levels more than 34.1% the depression effect of fertilizer on plant growth should be expected as shown by the treatment PU65, N: 44.04%. However, there were investigators who mentioned positive effects of heavy N-application on plant growth [48].

Carbohydrate content (%). The carbohydrate content in leaves of tomato plants fertilized with PU fertilizer at 4 and 7 weeks is shown in Figure 8. The treatment plants with all PU fertilizers resulted in high carbohydrate content in leaves compared with the control plants. The carbohydrate content increased with increasing nitrogen from 8.5 % (PU35) to 34.1 % (PU50) but decreased with nitrogen of

44.04 % (PU65). The increase of carbohydrate content is attributed to the increasing in the process of photosynthesis and pigments [49]. Furthermore, PU as N-fertilizer enhanced carbohydrate content in the leaves of tomato plants. The same behavior was reported by authors [50] when they studied the effect of different nitrogen fertilizers on the carbohydrate content in leaves of wheat.

Nitrogen, phosphorus and potassium content (%). Figure 9 shows the effect of a variety of nitrogen fertilizer (PU) on the nutrient percentage of tomato leaves at 4 and 8 weeks. PU fertilizer had a high significant effect on nitrogen percentage, no significance on phosphorus percentage, and low significance of potassium percentage in the tomato leaves. An increase in nitrogen content in fertilizer (PU), increased the nitrogen and potassium percentages in the leaves of tomatoes at 4 and 8 weeks. Nitrogen is the most important nutrient for the synthesis of proteins and the enhancement nutrient content in the leaves of plant including nitrogen and potassium content [18]. The obtained data was in accordance with those previously reported by authors [51,52] who reported that N-fertilizer increased the leaf nitrogen concentration.

Characteristics of flowers. Figure 10 indicates that the node number bearing the first flower as compared to the control increased due to nitrogen fertilizer (PU) application and this effect was more evident with PU50 (N: 34.1 %). Number of flower cluster per plant, number of flowers per cluster and number of flowers per plant significantly increased with increasing the content of nitrogen in PU fertilizers from 8.5% (PU35) to 34.1 % (PU50) and decreased with increasing content of nitrogen 44.04 % (PU65).

The greatest number of flowers per plant was observed when the tomato plants were fertilized with PU50 (N: 34.1 %) while the lowest number of flowers was observed when the plants were fertilized with PU65 (N: 44.04 %) (Figure 11). Authors [40-47] reported that tomato plants treated with nitrogen fertilizer produced higher number of flowers than the control plants. The increase flower numbers might be due to increased content of available nitrogen which promotes better vegetative growth and enhances flower of tomatoes. From the Figure 11, it is clear that the nitrogen fertilizer (PU) promotes the production of flowers up to PU50 (N: 34.1 %) at which further increase in the fertilizer do not bring a significant increase in the flowers

Characteristics of fruits

Number of fruits per plant. Fruit number is the most impressive feature of all physiological process and plant growth phenomenon that express the response of plants to applied substances.

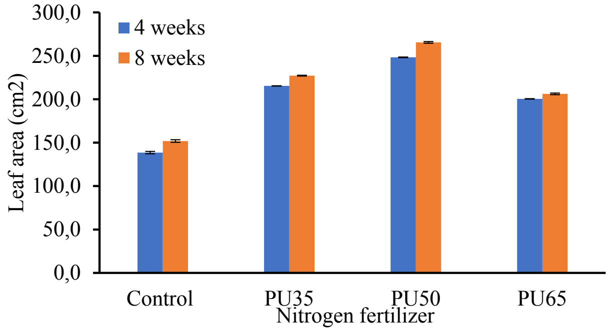

Figure 5 – Effect of nitrogen fertilizer on the leaf tomato area.

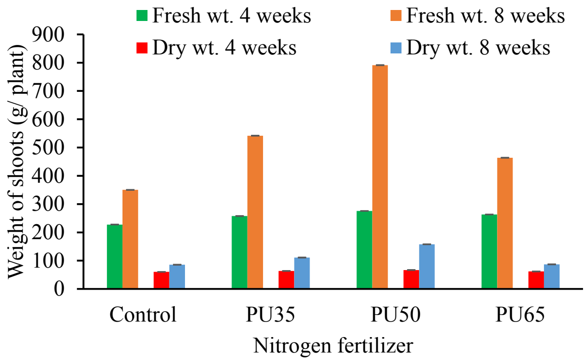

Figure 6 – Effect of nitrogen fertilizer on shoot fresh and dry weights per tomato plant.

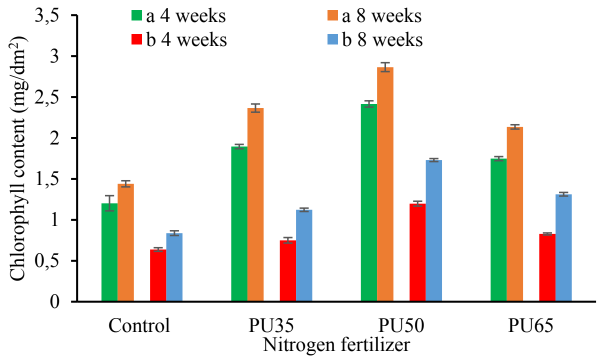

Figure 7 – Effect of nitrogen fertilizer on chlorophylls a and b in leaves of tomato plants.

Tomato plants fertilized with PU enhanced the number of fruits per plant than control plants as shown in Figure 12. Increasing the nitrogen content in PU fertilizer from 8.5 % (PU35) to 34.1 % (PU50) increased the number of fruits per plant from 27.73 to 29.85. At nitrogen level 44.04 % (PU65), the number of fruits was lower. This is attributed to the increase in the number of flowers per plan with increasing the content on nitrogen in the fertilizer. The result was in agreement with authors [53, 46, 31] who reported increased in the fruit number with increasing rate of nitrogen fertilizer. This could be attributed to the increased uptake of nitrogen and its associated role in chlorophyll synthesis (and hence the process of photosynthesis and carbon dioxide assimilation) leading to enhanced number of flowers and fruits.

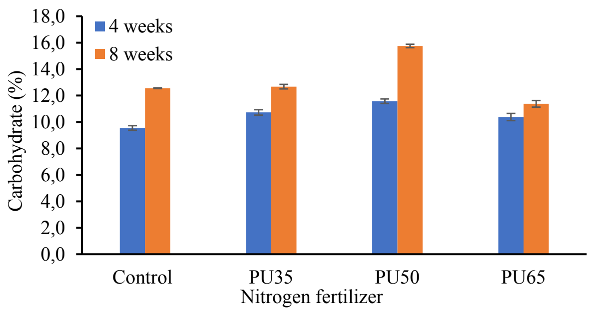

Figure 8 – Effect of nitrogen fertilizer on carbohydrate in leaves of tomato plant.

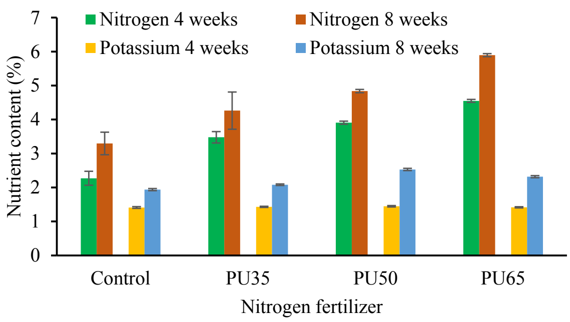

Figure 9 – Effect of nitrogen fertilizer on nitrogen and potassium percentages in leaves of tomato plants.

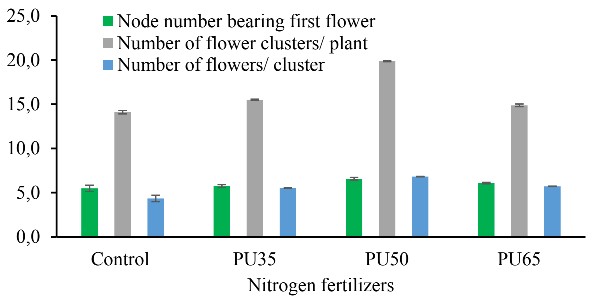

Figure 10 – Effect of N-fertilizer on node number bearing first flower, number of flower clusters per plant and number of flowers per cluster

Weight and volume of fruits. Data of the average fruit weight (Figure 13), volume (Figure 14) and shape index (Figure 15) produced by tomato plants fertilized with nitrogen fertilizer showed that PU fertilizer resulted in an increase in these parameters over control. Maximum values were recorded in tomato plants treated with PU50 (N: 34.1 %) and lowest values recorded in plants treated with PU65 (N: 44.04 %). Figure 13 shows the highest weight (69.8 gm) of fruits were obtained with PU50 (N: 34.1%) treatment, while lowest weight (50.83 gm) of fruits were observed for PU65 (N: 44.04 %) treatment.

Figure 14 shows that nitrogen fertilizers had a significant favorable effect on the fruit volume as compared to the control plants. The maximum significant values were obtained as a result of PU50 treatment. The increment was 20 % for for volume of fruit as compared to control plants.

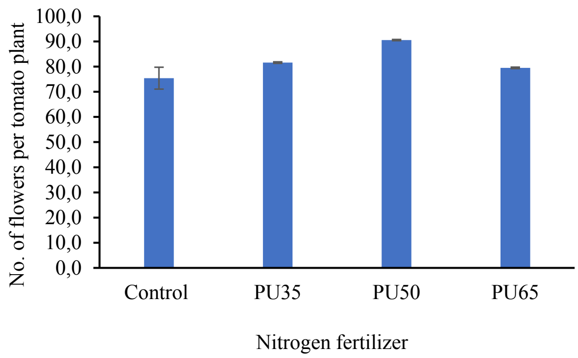

Figure 11– Effect of nitrogen fertilizer on number of flowers per tomato plant.

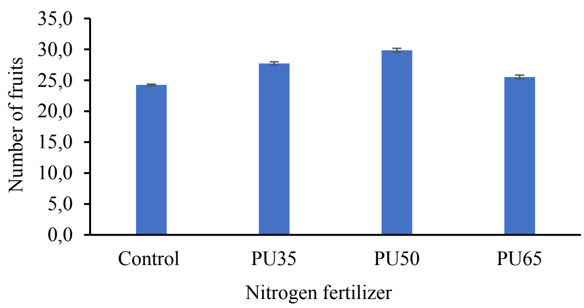

Figure 12 – Effect of nitrogen fertilizer on number of fruits per tomato plant.

The effects of the nitrogen fertilizers (PU) on the shape index of fruits showed an increase over the control except for treatment with PU50 (Figure 15). Tomato plants treatment with PU50 gave the highest shape of index fruits shape index (1.19) but PU65 gave the lowest shape index of fruits (1.12). The increased fruit weight, volume and shape index of tomato fruits under PU application could be attributed to the positive effect of nitrogen with balanced fertilization which increased weight, volume and shape index of fruit. The increments of the physical characters of tomato fruits response to nitrogen fertilizer were also reported by authors [54, 46, 47].

Chemical composition of fruits. Figure 16 shows that the SSC increased from 4.45 % to 5.48% with increasing nitrogen from 8.5 % (PU35) to 34.1 % (PU50) and decreased from 5.48% to 4.3% with increasing nitrogen of 34.1 % (PU50) to 44.04 % (PU65), but still more than the control. This might be due to the characteristics of N, which usually plays a role in increasing the amount of foliage, the quantity of chlorophyll, and ultimately the photosynthetic activity of the plant [46, 47]. However, Warner et al. (2004) [55] indicated that nitrogen did not affect the SSC of tomato fruits. Factors that might also influenced the solid content of tomato fruits include the number of fruits, rate of assimilates exported from leaves, rate of assimilates imported by fruits and fruit carbon metabolism.

The titratable acid of tomato fruits significantly increased with increasing nitrogen rate in PU fertilizer. Tomato plants fertilized with PU50 (N: 34.1 %) gave the highest percentage of acid (0.79 %) while plants fertilized with PU65 (N: 44.04 %) gave the lowest percentage of titratable acid (0.68 %) though higher than the control as shown on Figure 16. Wang et al. (2007) [56] reported that nitrogen was related to improved fruit shape, the reduction of ripening disorders, and an increase in fruit acid concentration, which subsequently improved the taste.

PU65 fertilizer reduced the ascorbic acid (vitamin C) and lycopene content (Figure 17). Rodriguez et al. (1994) [57] also reported that higher nitrogen fertilization decreased the vitamin C content and also worsened the fruit color. In this study, the highest values of ascorbic acid and lycopene contents were recorded with PU50 (N: 34.1 %).

This result was in agreement with previously reported results by Kobryń and Hallmann (2005) [57], whereas lycopene content increased with different nitrogen rates to 50 %. In fact, De Pascale et al. (2006) [12] suggested that since lycopene was synthesized by the isoprenoid pathway, nitrogen fertilizer enhanced the enzymes in this pathway therefore increasing the lycopene concentration in the fruits.

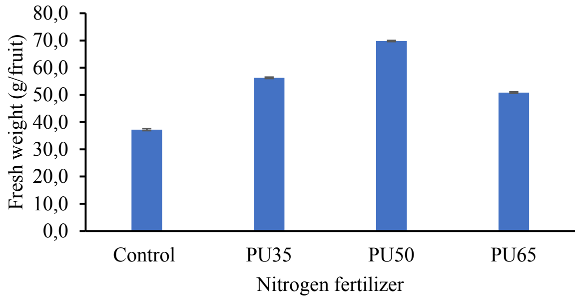

Figure 13 – Effect of nitrogen fertilizer on the fresh weight of tomato fruits.

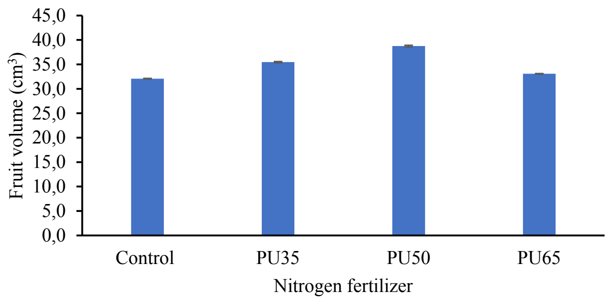

Figure 14 – Effect of nitrogen fertilizer on the volume of tomato fruits.

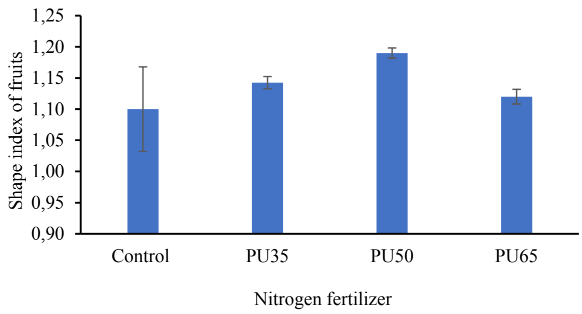

Figure 15 – Effect of nitrogen fertilizer on the shape index of tomato fruits

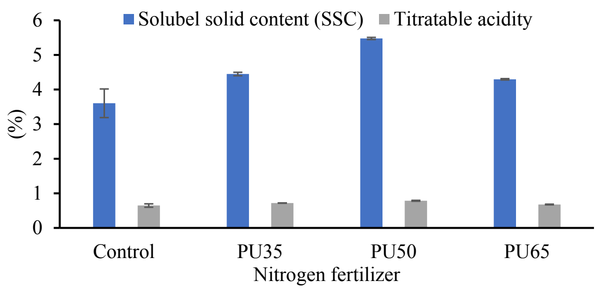

Figure 16 – Effect of nitrogen fertilizer on SSC and titratable acidity in tomato fruits.

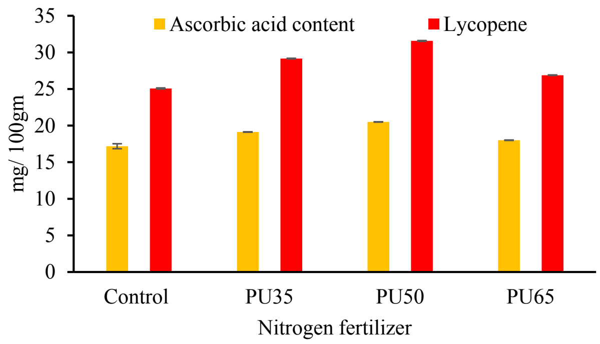

Figure 17 – Effect of nitrogen fertilizer on ascorbic acid and lycopene in tomato fruits.

Conclusion

The results revealed that nitrogen fertilizers based on polyvinyl alcohol blended with various ratios of urea [PU35 (N: 8.5 %), PU50 (N: 34.1%), PU65 (N: 44.0%)] affected vegetative growth of tomato plants. It was observed that PU35 treatment with nitrogen content (8.45%) was found to be the best treatment for the number of lateral branches and leaves per plant. Whereas the application of PU50 (nitrogen content 34.1%) resulted in a significant increase in other vegetative growth, chlorophylls a and b, flower and fruit characteristics higher than PU35, PU65 and control plants. Tomato fruit yields (23%) were best applied to PU fertilizers with a nitrogen content of 34.1% (PU50).

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