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Yield Performance and Heavy Metals Uptake of *Solanum lycopersicum*, Inoculated with *Pseudomonas aeruginosa* and *Trichoderma harzianum*

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Authors' contributions

This work was carried out in collaboration between both authors. Author SAO designed the study, wrote the protocol and wrote the first draft of the manuscript. Author AKA managed the analyses of the study, performed the statistical analysis and managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

The study was conducted to investigate the yield performance and heavy metals uptake of *Solanum lycopersicum* irrigated with contaminated stream water. For this purpose tomato plants was cultivated in soil irrigated with heavy metals contaminated stream water. Heavy metals content of the plant and yield performance of plant were examined. The heavy metal contaminated stream water was found to load the soil with heavy metals (Fe, Zn, Cu and Pb). The soil were treated with *Pseudomonas aeruginosa* and *Trichoderma harzianum*. The organisms was inoculated singly or in combination into experimental pots containing 3000 g of sterilized soil. Seeds of *Solanum*

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lycopersicum were raised in nursery for a period of 3 weeks and the treatments were applied before transplanting into experimental pots. Atomic Absorption Spectroscopy (AAS) method was used for detecting the amount of heavy metal in the stream before the experiment commenced. The heavy metals contaminated stream water was applied to the plants in measured quantities; 0, 5 and 10%. Yield data from the experiment were recorded and heavy metal uptake by the tomato plants were detected using the AAS method. It was evident from this experiment the plants treated with no inoculation of *Psedomonas aeruginosa* and/or *Trichorderma harzianum* produced lower yield and higher concentration of heavy metals in the harvested fruits. Plants treated with *Pseudomonas aeruginosa* produced better yield and lower concentration of heavy metals in the harvested fruits than other treatments applied at all levels of contaminated stream water sample. From this study, it can be concluded that the use of contaminated stream water could be a possible source of heavy metals in tomato and could pose danger to human health. The use of microorganisms for the treatment of heavy metals contaminated soil was effective for the growth and productivity of tomato.

Keywords: Solanum lycopersicum; Pseudomonas aeruginosa; Trichoderma harzianum.

1. INTRODUCTION

Heavy metals have recently received the attention of researchers all over the world, mainly due to their harmful effects on plant. Environmental pollution with heavy metals is increasing day by day due to urbanization and industrialization [1] and become a major global concern because of its toxicity and threat to human life and environment. Heavy metals are present in soil and aqueous streams as both natural components or as a result of human activity [2,3]. Human activities create waste and these wastes are handled, stored, collected and disposed of, which can pose risks to the environment and to public health [4,5,6]. Heavy metals are considered one of the most common and hazardous pollutants having a specific density of more than 5 g/cm3. Metals, like copper, iron, manganese, zinc are essential for life processes whereas others, like cadmium, nickel and mercury have no physiological function but often results in harmful disorders at a higher concentration [7]. Heavy metals may enter the human body through inhalation of dust, direct ingestion of soil and consumption of food plants grown in metal contaminated soil [8,9,10] and causes serious health hazards Vegetables are vital to the human diet and in particular, they provide trace elements and heavy metals [11]. Minor or trace elements are essential for good health if they come from an organic source or plant. In contrast, if they come from an inorganic or metallic source, they become toxic. The processes of plant growth depend on the cycle of nutrients which include trace elements, from soil to plant [11]. Vegetables, especially leafy vegetables, accumulate higher amounts of heavy metals because these metals are absorbed in their leaves. Tomato (*Solanum lycopersicum* L.) is one of the most important vegetables worldwide. World tomato production in 2001 was about 105 million tons of fresh fruit from an estimated 3.9 million ha. As it is a relatively short duration crop and gives a high yield, it is economically attractive and the area under cultivation is increasing daily. The importance of tomato fruits as good sources of ascorbic acid (Vitamin C), β-Carotene and mineral elements has been acknowledged [12]. Several studies have been conducted in order to evaluate the effects of different heavy metal concentrations on seedlings or adult plants [13]. The toxic effects of metals have also been intensively studied at the level of biochemical-physiological process such as photosynthesis [14], transpiration [15], enzyme activity [16] or metal accumulation in tissue [17]. Some heavy metals at low doses are essential micronutrients for plants, but in higher doses they may cause metabolic disorders and growth inhibition and yield productivity for most of the plants species [18,19]. The beneficial action of *Trichoderma* spp. is not limited to fighting pathogens; they have also been shown to be opportunistic plant symbionts, enhancing systemic resistance of plants [20,21], *Trichoderma harzianum* has potential in stimulating phytoremediation directly and indirectly and therefore, inoculation of plants with this fungus could be a feasible approach to enhance the degradation of hydrocarbons in polluted soil. *Trichoderma harzianum* has been shown to induce the production of larger and deeper root systems, and plants inoculated with *Trichoderma harzianum* also produce greater plant biomass. This interaction with plants as well as their rhizosphere competence leads to enhanced root proliferation, better growth, and protection of the plants against toxic chemicals, against which *Trichoderma* spp. themselves show a remarkable resistance. Hence, these fungi are promising agents that can be applied for remediation of polluted soil and water by treatment of appropriate plants with spores [22]. *Pseudomonas aeruginosa* are among the most competent rhizosphere colonizers of soil [23]. [24] have described the traits necessary for successful rhizosphere colonization, i.e motility and chemotaxis, specialized pilifor attachment to surfaces, lipopolysaccharides (LPS) and outer membrane integrity for efficient uptake of nutrients, ability to utilize specific exudate components, resistance to toxins, and other plants defenses. *Pseudomonas aeruginosa*, in general posses all these traits, which provide them with a salective advantage for exploiting the resources in the rhizosphere. [25] noted that various bacteria such as *Pseudomonas aeruginosa* produce surfactants that aid in the biodegradation. A recent study has found a *P. aeruginosa* strain that actually supports plant growth. This characteristic, along with the fact that *P. aeruginosa* can degrade polycyclic aromatic hydrocarbons, suggests the future uses of *P. aeruginosa* for environmental detoxification of synthetic chemicals and pesticides and for industrial purposes [26].

2. MATERIALS AND METHODS

2.1 Collection of Contaminated Water, Seeds and Microorganisms

Samples of heavy metals contaminated stream water was collected inclean plastic kegs from a flowing stream at the back of the Ife Iron and Steel Nigeria Limited along Ife-Ibadan expressway. The stream is situated at 7°30' Northern latitude and 4°28' Eastern longitude. Seeds of *Solanum lycopersicum* cultivar (ROMA VF) were obtained from Institute of Agricultural Research and Training, Moor Plantation, Ibadan while the microorganisms used in this experiment were collected from the Mycology unit of the Department of Crop Production and Protection, OAU, Ile-Ife.

2.2 Culturing of Organisms

A single colony of *P. aeruginosa* was isolated by subculturing on nutrient agar in Petri dishes and kept in the incubator for 48 hours at 37°C. Cells of *P. aeruginosa* were harvested from agar plates by flooding with sterile distilled water and standardized using a colorimeter to 10^8 CFU/ml. Spores of *Trichoderma harzianum* was subcultured by using potato dextrose agar in Petri dishes and kept in the incubator for 7 days at 37°C to a medium after which it was harvested by flooding with sterile distilled water. Spores of *T. harzianum* were harvested from agar plates by flooding with sterile distilled water and standardized using a colorimeter to 10^7 spores/ml.

2.3 Preparation of Sterilized Soil for Field Work

Top soil and river sand were mixed together and sieved before it was sterilized using an autoclave by heating for 5 hours at 131°C and left to cool for four (4) days.

2.4 Planting of Seeds and Contamination of Experimental Pots

This study was conducted in the screenhouse of Faculty of Agriculture, Obafemi Awolowo University, Ile-Ife. The seeds of *S. lycopersicum* were raised on nursery beds for a period of three weeks. Sterilized soil was used for this experiment, there were sixty (60) experimental pots. Each pot contained 3 kg of soil. The experimentalpots were divided into four sets. Each set has 15 experimental pots. *Pseudomonas aeruginosa* inoculum solution (30 ml) was poured into a hole that was made in the middle of a set of 15 experimental pots containing sterized soil before *S. lycopersicum* seedlings are transplanted to it. A hole was made in the next set of the 15 experimental pots and *Trichoderma harzianum* spore solution (30 ml) was poured into a hole that was made in the middle of the 15 experimental pots before *S. lycopersicum* seedlings are transplanted to them. The third set of 15 pots received dual inoculation of *Trichoderma harzianum* spore solution (15 ml) and *P. aeruginosa* innoculum before *S. lycopersicum* seedlings were transplanted into it. The final set of 15 pots acted as control with no inoculation of microrganisms at various levels. All the experimental pots arranged in a completely randomized design in the screenhouse. The contaminated stream water was applied at 0, 5 and 10% levelof concentration. The level of contaminated stream water concentration was quantified using the formula: percentage soil contamination = (Volume of polluted stream water applied / Volume of soil) x 100). Each treatments of the experiment was replicated three times. The experiment had two sets in which some pots were watered regularly with the contaminated stream water while some pots were watered only once with the contaminated stream water throughout the period of the experiment. Twenty four pots were watered with the contaminated stream water once during the experiment and another 24 pots watered daily with the contaminated stream water. The remaining 12 pots which served as the control experiment were watered daily with distilled water. Heavy metal uptake of the plants was detected using the AAS method while yield data such as number of fruits, weight of fruit and diameter of fruit was recorded at every harvest from 13 weeks after planting till the experiment was terminated at 15 weeks after planting.

2.5 Experiment (Treatment Layout)

The layout of the experiment is as follows;

Treatment 1- sterilized soil + *S. lycopersicum*
Treatment1d- sterilized soil + *S. lycopersicum* (2)
Treatment - sterilized soil + *Trichoderma harzianum* + *S. lycopersicum*
Treatment 2d- sterilized soil + *Trichoderma harzianum* + *S. lycopersicum* (2)
Treatment 3- sterilized soil + *Pseudomonas aeruginosa* + *S. lycopersicum*
Treatment 3d- sterilized soil + *Pseudomonas aeruginosa* + *S. lycopersicum* (2)
Treatment 4- sterilized soil + *T. harzianum* + *P. aeruginosa* + *S. lycopersicum*
Treatment 4d- sterilized soil + *T. harzianum* + *P. aeruginosa* + *S. lycopersicum* (2)

Note: (2) and d means daily wetting of pots with contaminated water

Each of the layouts contaminated at 0, 5, and 10% (v/w) contaminated stream water concentration was replicated thrice. The experimental pots were watered regularly to ensure adequate moisture for proper growth of the test plant.

2.6 Yield Data

The following yield parameters of the plant were used to measure the effect of contamination and treatment in the experiment.

2.6.1 Number of fruits after treatment

The number of fruits on each plant was counted visually from 13 weeks after planting till the experiment was terminated at 15 weeks after planting.

2.6.2 Weight of fruit after treatment

Each harvested fruit was weighed using a digital weighing balance. The measurement was recorded in grams.

2.6.3 Diameter of fruit after treatment

The diameter of the fruits was measured after every harvest using a thread round the fruit and measuring the length of the thread on a meter rule.

3. RESULTS

The heavy metals properties of the stream water showed that heavy metals (Iron, Zinc, Copper and Lead) were present in high concentration in the stream water. Iron (Fe) had the highest concentration of 138.15 mg/L followed by zinc (Zn) which had a concentration of 68.4 mg/L. Copper had a concentration of 8.9 mg/L while Lead had the lowest concentration of 7.89 mg/L.

3.1 Yield Data

The yield data of *S. lycopersicum* was taken from 13 WAP to 15 WAP across all the treatments at different levels of contamination with contaminated stream water which showed yield results. The yield data parameters include.

3.1.1 Number of fruits produced under different treatments

For 0% level of contaminated stream water concentration, treatment 3 (with innoculation of *P. aeruginosa*) produced the highest number of fruits with nine (9) *S. lycopersicum* fruits while treatment 2 (with inoculation of *T. harzianum*) and treatment 4 (with dual inoculation of *T. harzianum* and *P. aeruginosa*) produced three (3) *S. lycopersicum* fruits having the same number of fruits. At 13WAP, treatment 3 produced the highest number of fruits while treatment 1 (with no inoculation of micro-organism) produced the lowest number of fruits with 4 *S. lycopersicum* fruits (Table 1). For 5% level of contaminated stream water concentration, at 13 WAP, treatment 1d (with no inoculation of micro-organism) and treatment 2(with inoculation *T. harzianum*) produced two (2) fruits having same number of fruits (Table 2). Similarly, treatment 1 (with no inoculation of micro-organism) and treatment 3 (with inoculation of *P. aeruginosa*) produced the highest number of fruits producing 7 fruits.

Treatment 3 and treatment 3d produced the same number of fruits, also treatment 2, treatment 2d and treatment 4 also produced the same number of fruits at 14 WAP. Treatments 1, 1d and 4d also produced the same number of fruits at 14 WAP. Treatment 1 did not produced any fruit at 15 WAP but treatment 3d produced the highest number of fruits at 15 WAP.

For contaminated stream water concentration at 10%, treatment 1 and treatment 1d produced the same number of fruits ,also treatments 4 and 4d produced the same number of fruits, both producing three (3) fruits at 13 WAP (Table 3). Treatment 3d had the highest number of fruits producing 6 fruits. From 14 WAP to 15 WAP, treatment 1 and treatment 1d did not produce any number of fruit. At 15 WAP treatment 3 and treatment 4 produced the highest number of fruits both producing the same number of fruits.

3.1.2 Weight of fruits produced under different treatments

For 0% level of contaminated stream water concentration, treatment 3(with inoculation of *P. aeruginosa*) had the highest value of weight of fruit with 23.0 g followed by treatment 1(with no inoculation of micro-organism) with 12.4 g weight of fruit while treatment 4 (with dual inoculation of *T. harzianum* and *P. aeruginosa*) having the lowest weight of fruit with 5.7 g at 13 WAP. There was an increase in the weight of fruit in treatment 1 and treatment 4 while treatment 2 and treatment 3 showed a decrease in weight of fruit from 14 WAP to 15 WAP. At 15 WAP, treatment 1 had the highest value of weight of fruit while treatment 2 had the lowest value in weight of fruit (Table 4). For contaminated stream water concentration at 5%, treatment 3d (with inoculation of *P. aeruginosa*) had the highest value of weight of fruit with 45.5 g followed by treatment 4d (with dual inoculation of *T. harzianum* and *P. aeruginosa*) with 35.2 g weight of fruit while treatment 2 (with inoculation of *T. harzianum*) had the lowest weight of fruit with 16.1 g at 13 WAP. From 14 WAP to 15 WAP there was an increase in the weight of fruit in all the treatments except treatment1. At 15 WAP, treatment 3d had the highest weight of fruit (Table 5).

For 10% level of contaminated stream concentration, treatment 3d had the highest value in weight of fruit with 39.3 g while treatment 1d has the lowest weight of fruit with 5.3 g. Treatment 1 and treatment 1d had no weight of fruit from 14 WAP to 15 WAP since they produced no fruit from 14 WAP to 15 WAP (Table 6). There was an increase in weight of fruit in treatment 2, treatment 2d, treatment 3, treatment 4 and treatment 4d from 14WAP to 15 WAP. At 15 WAP, treatment 3 had the highest value in weight of fruit followed by treatment 4.

3.1.3 Diameter of fruits produced under different treatments

For 0% level of contaminated stream water concentration, treatment 2 and treatment 3 had the same value in diameter of fruit at 13 WAP. There was a decrease in fruit diameter in all the treatments from 13 WAP to 14 WAP. At 15 WAP, treatment 1 had the highest diameter of fruit with 20.2 cm followed by treatment 4 with 15.5 cm while treatment 2 had the lowest diameter of fruit with 14.0 cm (Table 7). For 5% level of contaminated stream water concentration, at 13 WAP, treatment 3 had the highest diameter of fruit with 26.0 cm while treatment 1 d had the lowest diameter of fruit with 14.0 cm. There was an increase in diameter of fruit in treatments 2,

Table 1. Total number of fruits produced and mean number of fruits under different treatment with 0% contaminated stream water concentration

Treatment	Age after planting					
	13		14		15	
	Total number	Mean	Total number	Mean	Total number	Mean
1-SS + TP	6	2	3	1	4	1.3
2-SS + TH + TP	3	1	3	1	2	0.6
3-SS + PA + TP	9	3	4	1.3	3	1
4-SS+TH+PA+TP	3	1	2	0.6	2	0.6

Legend: SS: Sterilised soil; TP: Test plant; TH: Trichoderma harzianum; PA: Pseudomonas aeruginosa; Treatment 1 – Sterilised soil + Solanum lycopersicum; Treatment 2 – Sterilised soil + T. harzianum + Solanum lycopersicum; Treatment 3 – Sterilised soil + P.aeruginosa +Solanum lycopersicum; Treatment 4 – Sterilised soil + T. harzianum+ P. aeruginosa + Solanum lycopersicum

Table 2. Total number of fruits produced and mean number of fruits under different treatment with 5% contaminated stream water concentration

Treatment	Age after planting					
	13		14		15	
	Total number	Mean	Total number	Mean	Total number	Mean
1-SS + TP	4	1.3	1	0.3	-	-
1d-SS + TP	2	0.6	1	0.3	1	0.3
2-SS + TH + TP	2	0.6	2	0.6	4	1.3
2d-SS+TH +TP	3	1	2	0.6	3	1
3- SS + PA + TP	4	1.3	4	1.3	5	1.6
3d-SS + PA + TP	7	2.3	4	1.3	7	2
4-SS+TH+PA+TP	3	1	2	0.6	3	1
4d-SS+TH+PA+TP	5	1.6	1	0.3	5	1.6

Table 3. Total number of fruits produced and mean number of fruits under different treatment with 10% contaminated stream water concentration

Treatment	Age after planting					
	13		14		15	
	Total number	Mean	Total number	Mean	Total number	Mean
1-SS + TP	1	0.3	-	-	-	-
1d-SS + TP	1	0.3	-	-	-	-
2-SS + TH + TP	4	1.3	3	1	2	0.6
2d-SS+TH +TP	2	0.6	3	1	3	1
3- SS + PA + TP	4	1.3	3	1	4	1.3
3d-SS + PA + TP	6	2	3	1	3	1
4-SS+TH+PA+TP	3	1	2	0.6	4	1.3
4d-SS+TH+PA+TP	3	1	1	0.3	2	0.6

Table 4. Total weight of fruit produced (g) and mean weight of fruit (g) under different treatment with 0% contaminated stream water concentration

Treatment	Age after planting					
	13		14		15	
	Total weight	Mean	Total weight	Mean	Total weight	Mean
1-SS + TP	37.1	12.4	16.3	5.4	19.9	6.6
2-SS + TH + TP	22.5	7.5	19.2	6.4	13.5	4.5
3-SS + PA + TP	69.1	23	27.2	9.1	18.6	6.2
4-SS+TH+PA+TP	17.1	5.7	13.5	4.5	13.7	4.6

Table 5. Total weight of fruit (g) produced and mean weight of fruit (g) under different treatment with 5% contaminated stream water concentration

Treatment	Age after planting					
	13		14		15	
	Total Weight	Mean	Total Weight	Mean	Total Weight	Mean
1-SS + TP	25	8.3	6.5	2.1	-	-
1d-SS + TP	19.7	6.5	5.3	1.7	6.5	2.1
2-SS + TH + TP	16.1	5.4	14.0	4.7	26.5	8.8
2d-SS+TH +TP	18	6.0	13.3	4.4	22.3	7.4
3- SS + PA + TP	28.6	9.5	27.6	9.2	36.5	12.2
3d-SS + PA + TP	45.5	15.2	28.3	9.4	50.1	16.7
4-SS+TH+PA+TP	19.6	6.5	13.8	4.6	19.6	6.5
4d-SS+TH+PA+TP	35.2	11.7	5.3	1.7	33.3	11.1

2d, 3, 3d, 4 and 4d from 14 WAP to 15 WAP. Treatment 1 had no diameter of fruit at 15 WAP but treatment 3 had the highest diameter of fruit with 26.7 cm (Table 8). For contaminated stream water concentration at 10%, at 13 WAP treatment 3 had the highest diameter of fruit with 27.3 cm while treatment 1 d had the lowest diameter of fruit with 7.5 cm. Treatments 1 and 1 d had no diameter of fruit from 14 WAP to 15 WAP since they produce no fruit. There was a decrease in diameter of fruit in treatments 2 and 3d from 14 WAP to 15 WAP. At 15 WAP, treatment 3 had the highest diameter of fruit followed by treatment 3 d (Table 9).

3.2 Heavy Metal Content of *S. lycopersicum* Fruit after Harvest

The heavy metal analysis of the fruits revealed that treatments with no inoculation of micro-organism had the highest level of heavy metals as the concentration of contaminated stream water increased. Treatment 1d had the highest level of iron at 5% and 10% concentration while treatment 3 had the lowest level of iron at the same concentration (Fig. 1). At 10% concentration of contaminated stream water, treatment 1d had 4.08 ppm concentration of zinc which indicated that it had the highest concentration while treatment 3 had 2.18 ppm concentration of zinc and also showed that it had the lowest concentration of zinc at the same concentration. The order of increase in zinc concentration across the treatments is 1d>1>4d>4>2d>2>3d>3 and 1d>1>4d>4>2d>2>3d>3 at 5% and 10%

Table 6. Total weight of fruit (g) produced and mean weight of fruit (g) under different treatment with 10% contaminated stream water concentration

Treatment	Age after planting					
	13		14		15	
	Total weight	Mean	Total weight	Mean	Total weight	Mean
1-SS + TP	6.1	2.0	-	-	-	-
1d-SS + TP	5.3	1.7	-	-	-	-
2-SS + TH + TP	28.4	9.5	16.3	4.4	11.6	3.9
2d-SS+TH +TP	14.2	4.7	18.3	6.1	19.1	6.4
3- SS + PA + TP	25.5	8.5	19.0	6.3	31.0	10.3
3d-SS + PA + TP	39.3	13.1	20.5	6.8	18.9	6.3
4-SS+TH+PA+TP	16.0	5.3	9.3	3.1	23.1	7.7
4d-SS+TH+PA+TP	13.2	4.4	5.8	1.9	12.6	4.2

Table 7. Total diameter of fruit produced (cm) and mean diameter of fruit (cm) under different treatment with 0% contaminated stream water concentration

Treatment	Age after planting					
	13		14		15	
	Total diameter	Mean	Total diameter	Mean	Total diameter	Mean
1-SS + TP	22.0	7.3	20.0	6.7	20.2	6.7
2-SS + TH + TP	22.5	7.5	15.2	5.1	14.4	4.8
3-SS + PA + TP	27.5	9.1	23.0	7.7	14.0	4.7
4-SS+TH+PA+TP	22.5	7.5	14.5	4.8	15.5	5.2

Table 8. Total diameter of fruit (cm) produced and mean diameter of fruit (cm) under different treatment with 5% contaminated stream water concentration

Treatment	Age after planting					
	13		14		15	
	Total diameter	Mean	Total diameter	Mean	Total diameter	Mean
1-SS + TP	17.6	5.8	15.0	3.0	-	-
1d-SS + TP	14.0	4.7	7.2	2.4	7.0	2.1
2-SS + TH + TP	17.0	5.7	15.7	5.2	17.0	5.7
2d-SS+TH +TP	14.5	4.8	13.0	4.3	15.7	5.2
3- SS + PA + TP	26.0	8.7	17.0	5.7	26.1	8.7
3d-SS + PA + TP	25.5	8.5	22.7	7.6	26.7	8.9
4-SS+TH+PA+TP	22.7	7.6	14.5	4.8	18.6	6.2
4d-SS+TH+PA+TP	24.4	8.1	8.0	2.6	19.5	6.5

Table 9. Total diameter of fruit (cm) produced and mean diameter of fruit (cm) under different treatment with 10% contaminated stream water concentration

Treatment	Age after planting					
	13		14		15	
	Total diameter	Mean	Total diameter	Mean	Total diameter	Mean
1-SS + TP	10	3.3	-	-	-	-
1d-SS + TP	7.5	2.5	-	-	-	-
2-SS + TH + TP	16.5	5.5	20.0	6.7	13.0	4.3
2d-SS+TH +TP	8.5	2.8	15.0	5.0	20.0	6.7
3- SS + PA + TP	27.3	9.1	19.0	6.3	21.4	7.1
3d-SS + PA + TP	23.8	7.9	23.0	7.7	19.4	6.5
4-SS+TH+PA+TP	14.5	4.8	14.5	4.8	18.0	6.0
4d-SS+TH+PA+TP	18.0	6.0	6.5	2.2	13.5	4.5

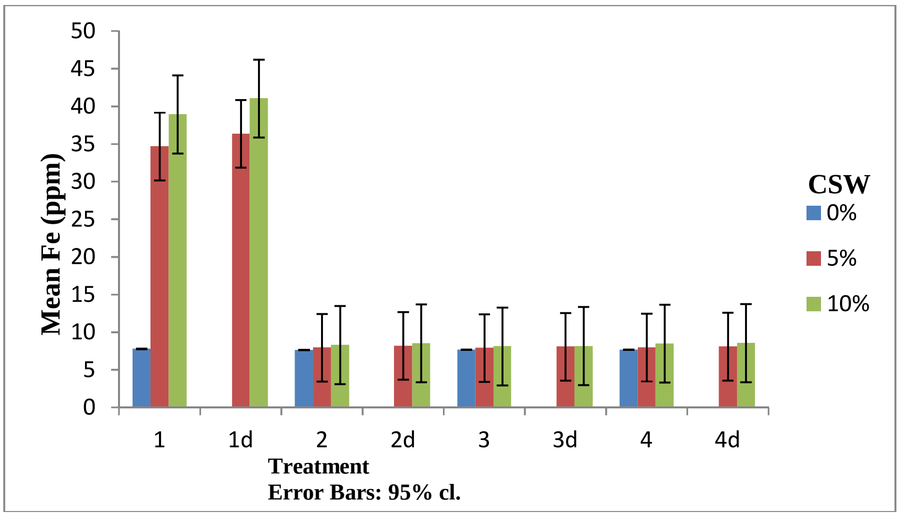

Fig. 1. Iron (ppm) content of *S. lycopersicum* fruit across all the treatments

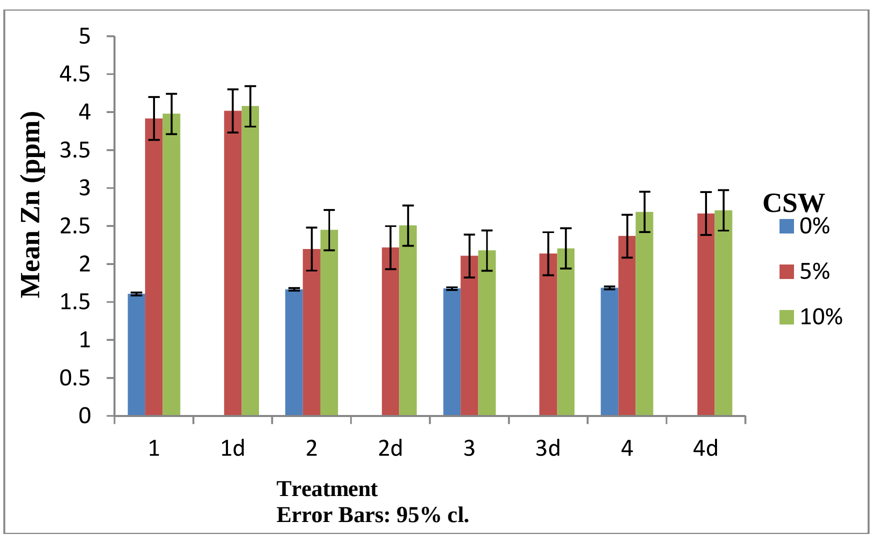

Fig. 2. Zinc (ppm) content of *S. lycopersicum* fruit across all the treatments

concentration (Fig. 2). Treatments 1 and 2 had the lowest copper level at 0% with the value of 0.17 pm. At 5% and 10% concentration of contaminated stream water, treatment 1d had the highest level of copper concentration followed by treatment 1 while treatment 3 had the lowest level of copper concentration followed by treatment 3d (Fig. 3). Lead concentration was highest in treatment 1d at 5% and 10% concentration while it was lowest in treatment 3 at the same concentration (Fig. 4). Treatments 3 and 3 d inoculated with *P. aeruginosa* had lower levels of the heavy metal in the harvested fruits when compared to treatments 4 and 4d treated with dual inoculation of *T. harzianum* and *P. aeruginosa.*

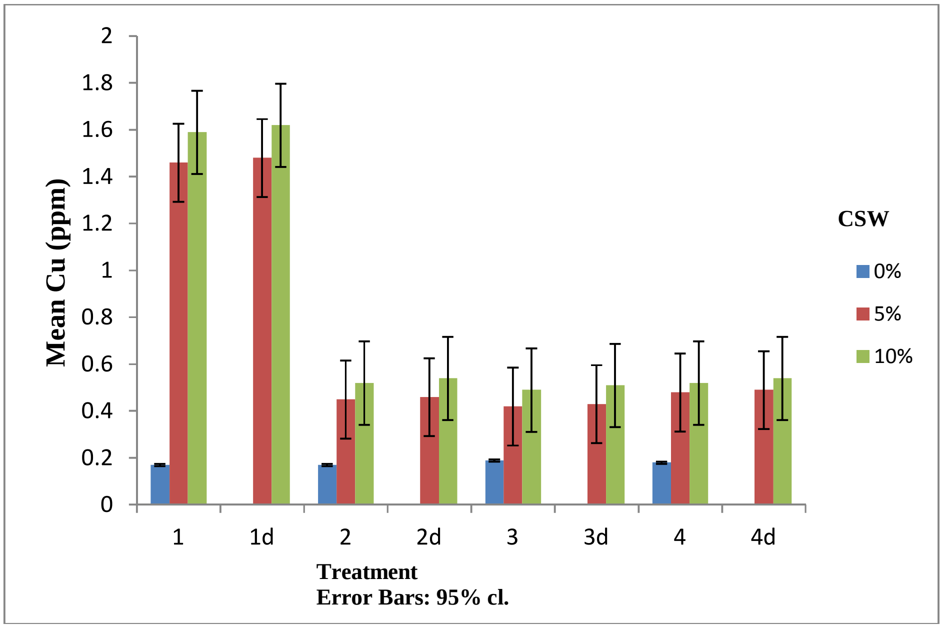

Fig. 3. Copper (ppm) content of *S. lycopersicum* fruit across all the treatments

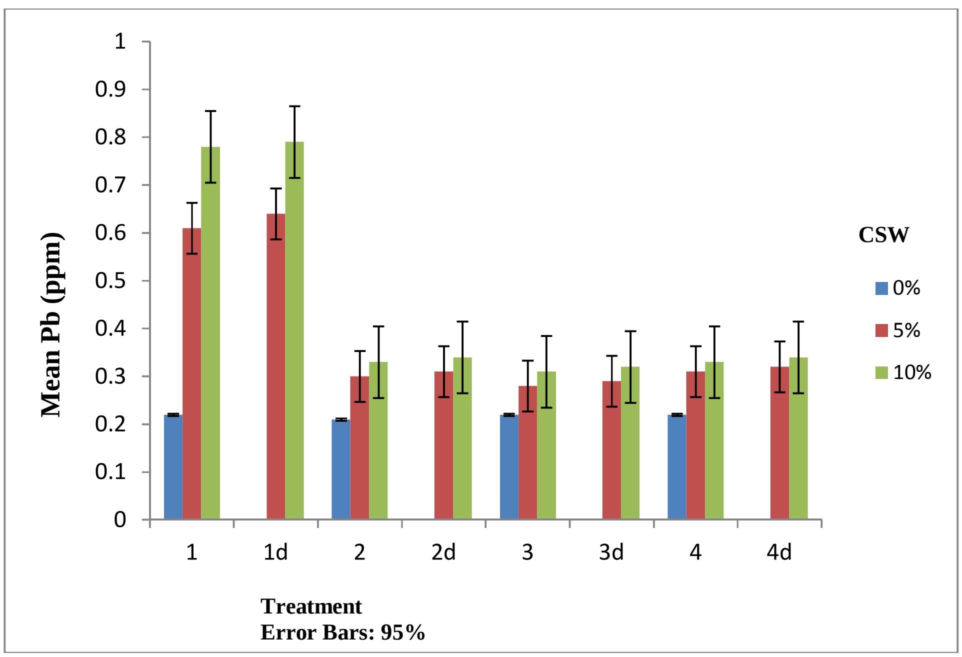

Fig. 4. Lead (ppm) content of *S. lycopersicum* fruit across all the treatments

4. DISCUSSION

Solanum lycopersicum grown in soil without contaminated stream water were found to grow better than those from contaminated soil. This shows that the contaminated stream water hinders the development and growth of the plant. Some of the direct toxic effects caused by high metal concentration include inhibition of cytoplasmic enzymes and damage to cell structures due to oxidative stress [27,28]. These toxic effects (both direct and indirect) could lead to a decline in plant growth which sometimes results in the death of plant [29]. It further denotes that soil polluted with contaminated stream water are low in fertility and nutrient hence, does not support adequate plant growth and development. The results obtained from this study indicates that the harvested fruits from soil samples with no inoculation of microorganisms contained higher levels of heavy metals (Iron, Zinc, Copper and Lead) in comparison with harvested fruit from soil samples with inoculation of one or two microorganisms. However soil samples inoculated with *P. aeruginosa* showed the lowest concentration of heavy metals in *S. lycopersicum* fruits. This study confirmed the reports by [30], who found that tomatoes could accumulate high levels of heavy metals in the edible part. Heavy metal accumulation is known produce significant physiological and biochemical responses in vascular plants [31]. The results obtained from this study showed that *S. lycopersicum* cultivated on soil samples with no inoculation of microorganisms at 5% and 10% concentration of contaminated stream water produced the lowest fruit yield (number of fruits, fruit diameter and weight of fruits). Treatments with *P. aeruginosa* inoculation were found to produce the highest fruit yield at 0%, 5% and 10% concentration of contaminated stream water. Treatments with a combination of *T. harzianum* and *P. aeruginosa* was also discovered to produce a higher number of fruits than treatments with single inoculation of *T. harzianum* The reduction of growth parameters in soil samples with no inoculation of microorganisms could be linked to the production of lower yield of fruits. Also the higher level of heavy metals uptake by the plants could be a determinant in the number of fruits produced. This is in agreement with report from [32] which noted that there is a direct relationship between heavy metals concentration and morphological and yield response of plants. The accumulation of heavy metals in plant tissues might cause reduction in biochemical response and physiological activities of plants resulting in lower biomass and yield [33]. Also the results in this study showed that *P. aeruginosa* used in this work did not only transform the heavy metals but also improved the growth and yield of *S. lycopersicum* fruits. There is also a positive relationship between *T. harzianum* and *P. aeruginosa* in enhancing the growth and yield of *S. lycopersicum*. Yield also has significant and negative relationship with concentrations of Cu, Pb, Zn, Fe, Cd and Cr in root and shoot of plants [34]. It was revealed that at higher concentration of contaminated stream water, the yield of the fruits was adversely affected. The results obtained from this study indicates that the harvested fruits from soil samples with no inoculation of microorganisms contained higher levels of heavy metals (Iron, Zinc, Copper and Lead) in comparison with harvested fruit from soil samples with inoculation of one or two microorganisms. However soil samples inoculated with *P. aeruginosa* showed the lowest concentration of heavy metals in *S. lycopersicum* fruits. This study confirmed the reports by [30], who found that tomatoes could accumulate high levels of heavy metals in the edible part. Vegetable crop plants have high ability to accumulate metals from the environment, which may pose risks to human health when they are grown on or near contaminates lands and consumed. Metal accumulation in plant depends on plant species, growth stages, types of soil and metals, soil conditions, weather and environment [35,36,37]. Thus, accumulation of heavy metals in the edible parts of vegetables represents a direct pathway for their incorporation into the human food chain [38]. Metal levels in soils were considered to be higher than those of the tomato leaves and tomato fruits. This is an indication that the contamination of the vegetables was through the soil. These elevated concentrations of metals were attributed to the contaminated stream water irrigation.

5. CONCLUSION

This study was able to observe the productivity and heavy metal uptake of tomato fruits that took place under the different experimental treatments. It showed that use of *P. aeruginosa* and/or *T. harzianum* in the soil were able to tolerate physiological stress as a result of the heavy metal polluted environment. The presence of *P. aeruginosa* and *T. harzianum* were able to effectively transform the heavy metals in the soil and increase the yield of *S. lycopersicum*. The results from this study indicates that there is a serious potential health risk associated with heavy metals in tomato by using contaminated water for irrigation by farmers for tomato production.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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