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Effect of Ultrasonic Atomizer on the Yield and Yield Components of Tomato Grown in a Vertical Aeroponic Planting System

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Abstract
Aeroponic planting is proved to be the one of the most efficient growing environments for many vegetable crops. In this technique, plants are cultivated in absence of soil and the required nutrients are directly supplied to the roots through a fogging system. In modern sprayers, water is atomized by means of ultrasound waves. The aim of the present study was to investigate the effect of ultrasound waves on the nutrient solution and on yield and some yield components of tomato grown in a vertical aeroponic planting system. The investigation was conducted using a 3×3 factorial experiment based on a completely randomized design. The considered factors were ultrasonic frequency at three levels of 50 kHz, 107 kHz and 2.1 MHz and the fogging duration at three levels of 10, 15 and 20 min. The results indicated that, at frequency of 50 MHz, the nutrient solution had the lowest EC equivalent while the pH of the nutrient solution reached its highest value at 2.1 MHz. Generally, both EC and pH value of the nutrient solution were elevated by increase in the wave frequency, but they did not show a definite trend by changes in fogging duration. The ANOVA indicated that the interaction effect of the ultrasound frequency and fogging period had significant effect on the plant height, root weight and length, fruit weight, fruit length, plant yield and system performance. In general, the measured yield components decreased as frequency of the waves increased and the best results were obtained at 50 kHz frequency and 15 min fogging period.

Keywords: Aeroponic planting, Ultrasonic Atomizer, Greenhouse, Tomato, Yield.

Introduction

Destruction of the agricultural lands as a result of global climate changes and the scarcity of water resources have posed serious challenges to the agricultural sector for food supply (Li et al., 2016). Precise agriculture and the use of high density and greenhouse culture are considered to be the modern agricultural techniques that can partly compensate the deficiencies in agricultural inputs. In this way, farmers can provide more crops per unit of area and get their crops to the market at any time of the year.

Improved greenhouse techniques such as hydroponic and aeroponic are currently the

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most successful innovations that are currently used in some greenhouses and are still under investigation by many researchers (Lakkireddy et al., 2012). In hydroponic technology, plants are cultivated in the absence of soil and the dissolved nutrients are directly supplied to the plants by a spraying system (Reyes et al., 2012). The benefits of this cultivation method include full control of the nutrient concentration and supply, and prevention from many diseases and infections that are transmitted from soil to the plant, and consequently producing a plant with increased crop yield and high quality (Raviv and Lieth, 2007; Valenzano et al., 2008).

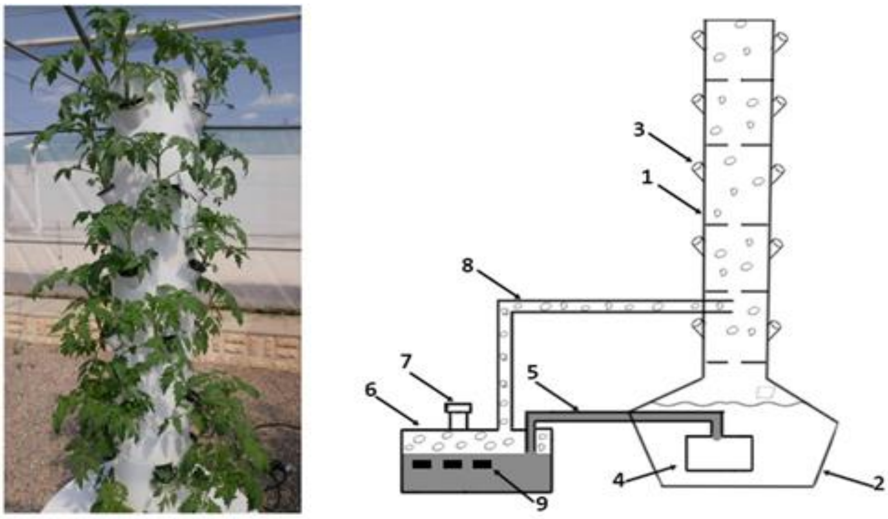
On the other hand, aeroponics technology, as a substitute for hydroponic culture, is a novel method for soilless culture that conserves water and fertilizer for growing the vegetables (Hayden et al., 2004). This method can effectively reduce the problems associated with root anoxia (Christie and Nichols, 2004). Some researchers have reported, in comparison with conventional cultures, aeroponics technology can reduce water consumption by 99%, nutrients by 50%, and the time span between planting to harvest by 45% (Barak et al., 1996).

The changes in pH and EC of nutrients solution during the growth period are considered as major problems in soilless culture systems (Hamlin and Barker 2006). The increase in the pH and EC of nutrient solutions that happens during the growing duration can adversely affect the plant yield. Therefore, during growing period the nutrient solution should be discarded. In some aeroponic systems nutrient solution is vaporized by means of ultrasonic transducers converting wave's energy to mechanical vibration. Some researchers have reported that ultrasonic waves can change the physical and chemical properties of the water containing nutrient solution, which can ultimately affect the plant yield (Gao et al., 2016; Doosti et al., 2012; Naddeo, et al., 2014; Lakhiar et al., 2018).

Tomato (*Lycopersicon esculentum Mill.*) is one of the most important crops for greenhouse production and also for human health and nutrition. Tomato is also widely cultivated in greenhouses throughout Iran and is considered as a valuable source of income for many farmers (Kalantari et al., 2015). There is a tendency toward the cultivation of this commodity by means of hydroponic or aeroponic systems. With the gradual increase in ultrasonic technology application for atomization of water, there is a need for further study on the effect of ultrasonic wave on aeroponic cultivation systems. The purpose of this study was to investigate the effect of ultrasound wave frequency and duration of fogging on pH and EC of nutrient solution as well as on the yield and yield components of this crop, grown in a vertical aeroponic system.

Materials and Methods

The experiments were carried out in the research greenhouse of the College of Agriculture, Shahid Bahonar University of Kerman in autumn 2018. For performing the experiments, 9 identical vertical aeroponic systems, as shown in Figure 1, were designed and built. Each system consisted of a polyethylene column of 20 cm diameter around it there were mounted 5 equally spaced rings of plant pots and each ring contained 4 plant pots. On each system a total of 20 plants could be planted. At the bottom of the column an 80-liter reservoir was embedded for holding the nutrient solution. Within the reservoir, a floating pump of 250 W was placed to transfer the nutrient solution to the ultrasonic fogging device. The ultrasonic transducers used in this device operated at different frequencies vaporize the solution through inducing vibration in the passing solution. The fogging duration was controlled by an electronic timer.



A B

Fig. 1. A) Picture of aeroponic system, B) Schematic diagram of the system: 1. System column; 2. Reservoir; 3. Plant pots; 4. Pump; 5. Pipe for transmitting nutrient solution to ultrasonic device; 6. Ultrasonic fogger; 7. Fan; 8. Pipe for transmitting fog to column; 9. Ultrasonic transducers

To perform the experiments, seeds of tomato were first placed in the cells containing rockwool and irrigated for 8 days. Then, the seedlings in the rockwool bed were transferred to the holes on the aeroponic platform. The nutrient solution in the reservoir was a Hoagland solution whose compounds are shown in Table 1. The solution was dissolved as 1 ml per liter of water and was poured into each reservoir in order to be transferred through the pipes to the reservoir of the ultrasonic fogger device. The amount of 50 mg of powdered nutrient (based on the company recommendation) was added to the water reservoir of each system once a week. Three tomato plants were randomly selected from each replication in each treatment. At the time of harvest (75 days after transplantation to the system) the tomato growth indices including fruit length and weight, root length, root dry weight and yield were measured. The changes in EC and pH values in the nutrient solution were measured once a week and their averages at the end of the growth period were used for data analysis.

The experiments were performed and analyzed using factorial experiments, based on completely randomized design, at probability levels of 0.05 and 0.01. In this investigation, the considered factors were: a) ultrasonic frequency, at three levels of 50 kHz, 107 kHz and 2.1 MHz, and b) the fogging period, at three time levels of 10, 15, and 20 min. Since there were a total of 9 systems, on each system one treatment was carried out and each row of planting pods was considered as a replicate. Considering four plants within each replicates, a total of 20 plants were used for each treatment. The ANOVA tests for the collected data were performed using Minitab 2014 and the required graphs were drawn in Excel 2014 environment.

Table 1. Concentration of food elements in the nutritional solution used in the aeroponic system (Tavassoli et al., 2010)

Nutrients	g/L	Nutrients	g/L
$Ca(NO_3)_2 .4H_2O$	11.81	$ZnSO_4 . 7H_2O$	0.22
KNO_3	5.05	$CuSO_4 . 5H_2O$	0.08
$NH_4(H_2PO_4)$	1.15	$H_2MoO_4 . H_2O$	0.02
$MgSO_4 .7H_2O$	4.39	$MnCl_2 . 4H_2O$	1.81
H_3BO_3	2.86		

Results

EC and pH values were affected by the both frequency of ultrasound waves and fogging period as shown in Table 2. The frequency and the fogging period interactions had significant effects on EC and pH values of the nutrient solution. Figures 2 and 3, respectively, show EC and pH changes as affected by these two factors. Figure 2 indicates that increasing the fogging period of the nutrient solution and decreasing the frequency of waves resulted in a decrease in EC of the nutrient solution.

Table 2. The ANOVA results for the effects of ultrasonic frequency and fogging duration on pH and EC of the nutrient solution

S.O.V	df	MS	
		pH	EC
Frequency of waves	2	**8467	**2808
period of time Fog	2	**9.2780	**245973
Frequency × Fogging time	4	**307.0	**200
Error	36	4300.0	41

**significantly differentns (P<0.01)

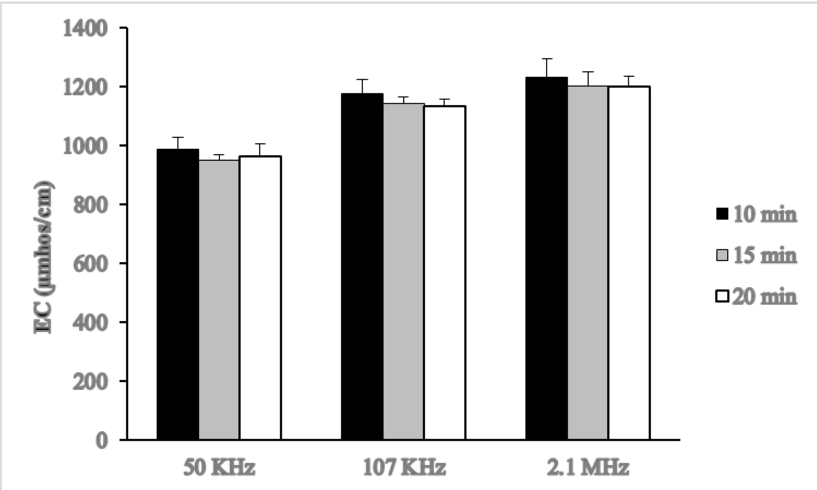


Fig. 2. Effect of ultrasonic frequency and fogging duration on EC of the nutrient solution

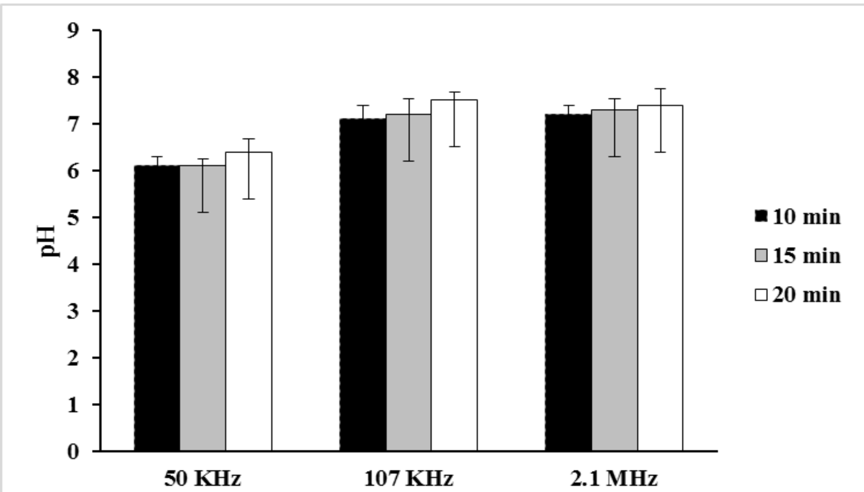


Fig. 3. Effect of ultrasonic frequency and fogging duration on pH of nutrient solution

The results of analysis of variance for the effects of ultrasonic frequency and fogging duration on yield and yield components of tomatoes are presented in Table 3. The results showed that the interaction effect of the frequency of ultrasonic waves and the fogging period of the nutrient solution had a significant effect ($P<0.01$) on the plant height, root length, root dry weight, fruit length, fruit weight, yield per plant, and system yield, at 0.01 level of probability.

Figure 4 shows the effects of different fogging periods and different frequencies of ultrasonic waves on plant height. The maximum plant height (165 cm) was achieved in fog spraying of the nutrient solution for 15 min at the lowest frequency produced by the ultrasonic device; and the lowest plant height (40 cm) was achieved in fogging of the nutrient solution for 20 min at the highest frequency.

Figure 5 shows a typical picture of roots for tomato plants 75 days after planting that typically reach up to 65 cm. Effect of different fogging periods and frequencies of ultrasonic waves on root length of tomato plants in the aeroponic system is shown in Figure 6. The maximum root length (71 cm) was obtained in the tomato plants cultured in the aeroponic system with the frequency of 50 kHz, that the fogging of nutrient solution was applied by an ultrasonic device on the root for 15 min; and the lowest root length (50 cm) was obtained in the tomato plants cultured in the aeroponic system with the frequency of 2.1 MHz, in which the fogging of nutrient solution was applied by an ultrasonic device on the root for 20 min (Fig. 6).

Table 3. The ANOVA results for the effects of ultrasonic frequency and fogging duration on yield and yield components of tomatoes

S.O.V	df	MS					
		plant height (cm)	Root length (cm)	Root dry weight (g)	Fruit length (cm)	Fruit weigh (cm)	Yield (kg)
Frequency of waves	2	7.35658**	37.1177**	69.1443**	3362.4**	96.2602**	91.1679**
period of time Fog	2	1317.0**	33.56**	81.77**	0.0296**	120.56**	158.08**
Frequency × period of time Fog	4	5.128**	37.49**	25.43**	0.0169**	9.29**	9.51**
Error	36	4.7	2.2	1.93	0.0039	0.57	3.53

**significantly differentns ($P<0.01$)

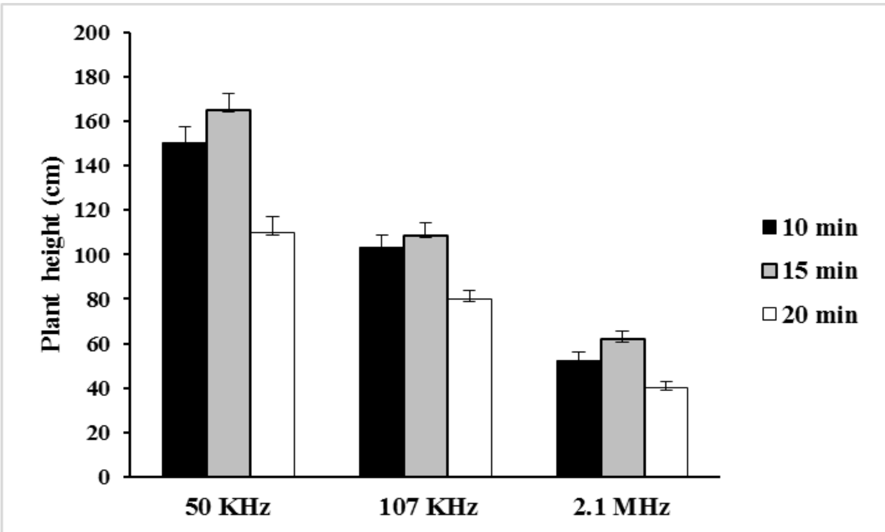


Fig. 4. Effect of ultrasonic frequency and fogging duration on plant height of tomato plants cultured in an aeroponic system

Fig. 5. Typical root system of tomato plant 75 days after sowing in an aeroponics system.

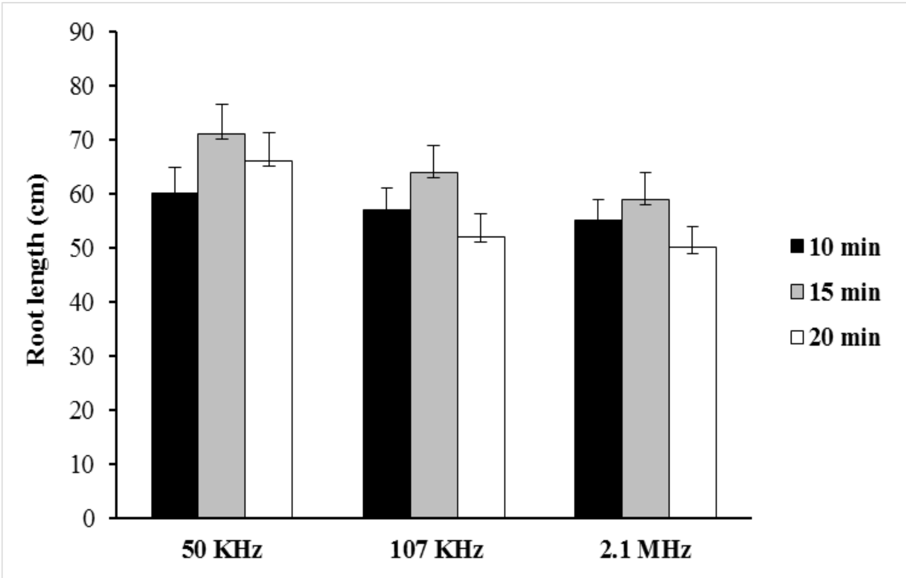


Fig. 6. Effect of ultrasonic frequency and fogging duration on root length of tomato plants cultured in an aeroponic system

Figure 7 shows the effect of fogging period and frequencies on root dry weight. The highest root dry weight of tomato plants (70 g) was achieved in the system with the frequency of 50 kHz and the fogging of nutrient solution for 15 min; and the lowest root dry weight (40 g) was acheived in 2.1 MHz and fog spraying duration of 20 min.

Figure 8 shows the influence of fogging periods and frequencies of ultrasonic on tomato fruit diameter. The interaction effects of the frequency of the waves and fogging duration on nutrient solution were significant ($P<0.01$) and the highest mean fruit length per plant (58 mm) was related to the aeroponic system at 50 kHz frequency and irrigation time of 15 minutes. The lowest mean of the fruit diameter per plant (53 mm) was related to the aeroponic system at a frequency of 2.1 MHz of ultrasonic waves and the irrigation time of 10 minutes.

The effects of fogging periods and frequencies of ultrasonic waves on fruit weight are shown in Figure 9. According to this results, the interaction effect of the frequency of fogging of nutrient solution on the irrigation period significantly affected fruit weight ($P<0.01$). The highest mean fruit weight (73 g) was related to the aeroponic system at the frequency of 50 kHz and irrigation period of 15 min. The lowest mean of fruit weight per plant (42 g) was related to the frequency of 2.1 MHz of ultrasonic waves and irrigation period of 10 min.

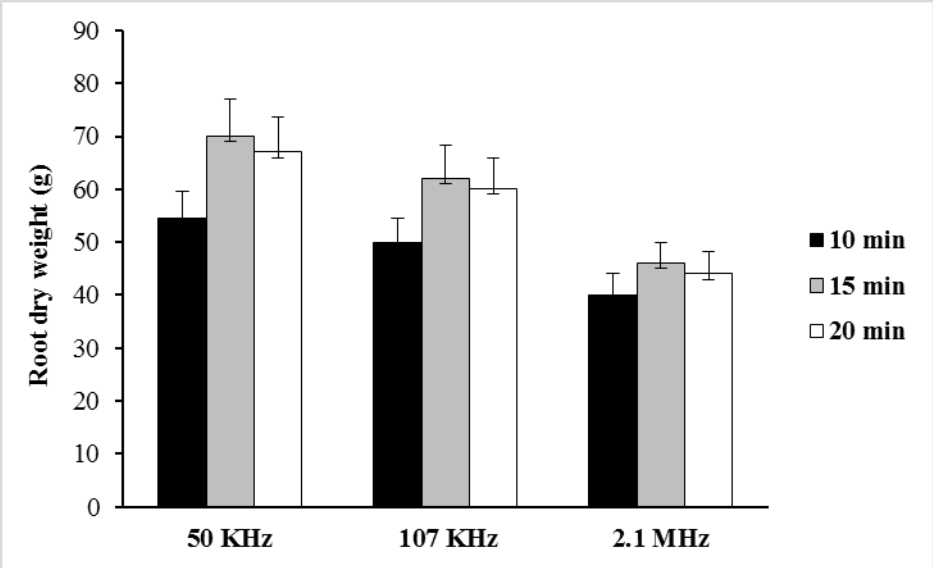


Fig. 7. Effect of ultrasonic frequency and fogging duration on root dry weight of tomato plants cultured in an aeroponic system

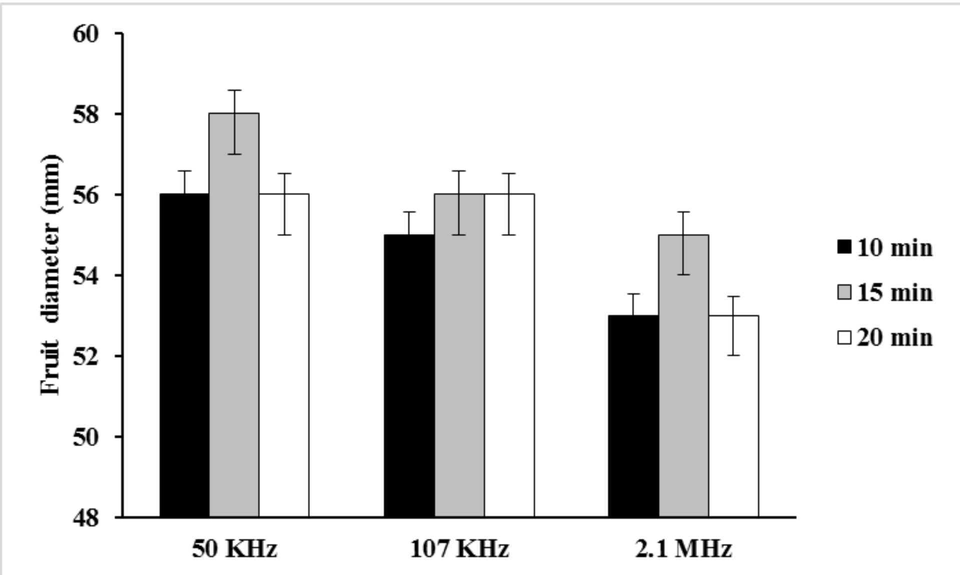


Fig. 8. Effect of ultrasonic frequency and fogging duration on fruit diameter of tomato plants cultured in an aeroponic system

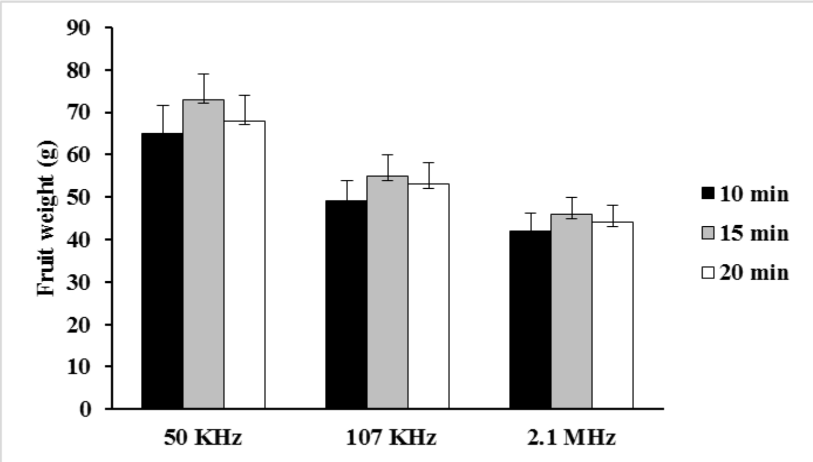


Fig. 9. Effect of ultrasonic frequency and fogging duration on fruit weight of tomato plants cultured in an aeroponic system

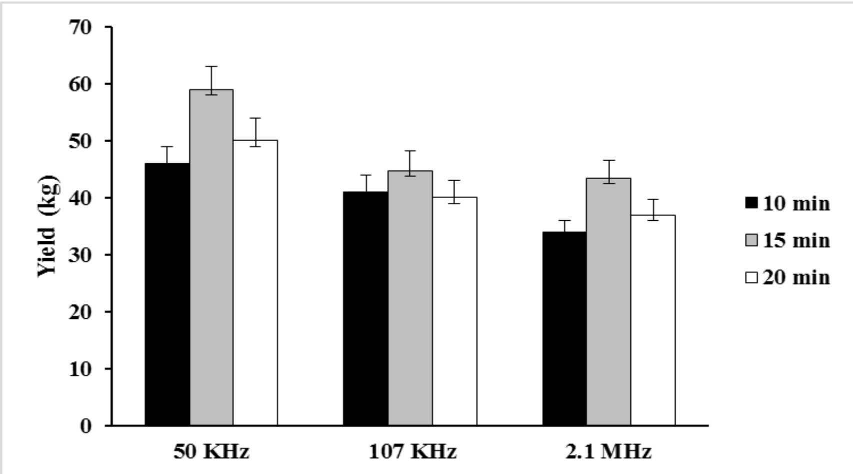


Fig. 10. Effect of ultrasonic frequency and fogging duration on yield of tomato plants cultured in an aeroponic system

Figure 10 shows the effect of fogging periods and frequencies of ultrasonic waves on plant yield. The interaction effect of ultrasonic frequency with the fogging period of nutrient solution significantly affected the tomato plant yield. The maximum plant yield was achieved in the fogging period of nutrient solution for 15 min at the frequency of 50 kHz. Moreover, the lowest plant yield was achieved in the fogging period of nutrient solution for 10 min at the highest frequency, which ultimately reduced the system yield in the plants that were treated with the frequency of 12.1 MHz and the period of 10 min, which resulted in the reduction of tomato yield to 34 kg (Fig. 10).

Discussion

In this study the effect of ultrasound waves on the nutrient solution and on the yield and yield components of tomatoes grown in a vertical aeroponic planting system were investigated. General speaking, the fogging period of 15 and 20 min at the frequency of 50 kHz significantly resulted in lower EC (949 µmho/cm) than the other treatments. Moreover, the pH value of the nutrient solution was enhanced by increasing the fogging period of the nutrient solution and frequency of waves. Therefore, aeroponic system by fog spraying of nutrient solution at a frequency of 2.1 MHz for 20 min had the highest pH compared to the other treatments. Lakhiar et al. (2018) also showed that the frequency of ultrasonic waves can cause alteration in the pH and EC of the nutrient solution.

The findings of this study indicated that the use of high-frequency ultrasonic waves for the average time of 15 min increased the plant height, which may be due to the decrease in pH and EC of the nutrient solution. These results are consistent with the findings of Hamlin and Barker (2006) and Lakhiar et al. (2018), who showed that by longer duration of ultrasonic waves at low frequencies reduces the pH of the nutrient solution for tomato production. In this case, it was found that higher frequency and longer fogging period resulted in an increase of pH of the nutrient solution in the roots rhizosphere, which can result in appearance of longer roots. Therefore, short application time (15 min) at lower frequency than 50 kHz, the root would be exposed to the nutrient solution with lower pH for a longer time, resulted in increase in the root length. Therefore, the positive effects of ultrasonic waves in proportion to other treatments are observed at lower frequencies. These results are consistent with the results obtained by Hayden (2006).

The analysis of pH data following the fog spraying of the nutrient solution on the roots for 15 min showed least effect of pH of the nutrient solution on the root growth, while the root dry weight was increased. Compared to the pH of the nutrient solution, the lower frequency did not have a significant effect on the root growth through the reduction of EC of the nutrient solution. These results are in consistent with the results reported by Lakhiar (2018) who stated that higher dry weight of the plant roots in systems with lower pH than the root dry weight of the nutrient solution with fluctuating pH.

The fog particles with high pH in the system at high frequency may reduce the fruit diameter, which has more impact compared to the EC of the nutrient solution. Therefore, it is evident that increasing the frequency of the ultrasonic waves would alter the EC of the nutrient solution and ultimately affect the fruit diameter. The sufficient nutrient solution with a lower pH for 15 min of fogging increased the fruit weight in the system. These results are in consistent with the findings of Lakhiar et al. (2018) that indicted of the suitability of irrigation with nutrient solution with low pH for tomato plant; they also reported that the average fogging period of nutrient solution will result in increase in the fruit weight.

This study showed that the yield of the vertical aeroponic planting system was significantly affected by fogging period and frequency of the ultrasonic wave. The highest yield of the aeroponic system was obtained at lower frequency with the period of 15 min, which was equal to 59 kg. Therefore, with increase in ultrasonic frequency the yield of plants decreases while an initial increase when going from 10 to 15 min fogging time and a decrease from 20 to 15 min would result in higher yield. Therefor an optimum recipe should be 15 min fogging period with lower frequencies.

Conclusion

In this study the effect of ultrasonic wave's frequency and fogging duration on nutrient solution and some yield components of tomato plants were investigated. The results showed that both pH and EC of the nutrient solution were adversely affected by increase in wave's frequency and fogging duration. The highest pH, close to 7.8, was reached at the frequency of 2.1 MHz with 20 min fogging duration while the highest EC was detected at the same frequency but with 10 min fogging duration. In addition, the interaction effect of the frequency and fogging period had significant effect on all considered yield components of tomato plants; these indices generally decreased with increase in frequency. The highest yield, 59 kg, was gained for the system with the frequency of 50 kHz and at the fogging period of 15 min. Even though this research indicates that the considered factors significantly affected the nutrient solution and yield components but more research is needed to find optimum frequency and fogging duration.

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