Impact of Rhizosphere's Thermal Change on the Development and Production of Hydroponically Grown Cucumber under Controlled Environment

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ABSTRACT---- ***The easier and more economical control of root-zone temperature (RZT) as compared to that of other environmental factors such as air temperature could be an effective solution to temperature stress for the crop plants in hydroponics. The present study was designed to investigate the effect of root-zone temperature on the growth and yield of cucumber (Cucumis sativus L.) plants in recirculating hydroponic system under greenhouse of dimension, 9m x 30m during three cropping periods of the year in Oman viz. summer (June-August), fall (September-November) and spring (February-May) during year 2016/2017 at Directorate General Of Agriculture and Livestock Research of the Ministry of Agriculture & Fisheries located at Rumais Barka of Oman. The plants were grown in perlite medium at root-zone cooled temperatures of 22°C, 25°C, 28°C treatments besides the control i.e. root-zone uncooled temperature of 33°C as control treatment. The treatments were arranged in Complete Randomized Design (CRD) with four replications. The results indicated that the crop at root-zone temperatures of 22°C and 25°C gave the superior performance in terms of plant height, leaf number, chlorophyll content, leaf area cm^2, fruit number/m^2, yield in ton per greenhouse (t/gh), fresh and dry weight of shoot and root with significant differences between the treatments in all three periods. Fruit yield varied from 4.5t/gh to 6.4t/gh for root-zone temperature (RZT) and from 4.2 t/gh to 6.8 t/gh for the cropping periods. The higher yields of 6.4 t/gh and 6.4t/gh were found under RZT of 22°C and 25°C, respectively and were significantly higher ($p<0.05$) than that under control (33°C; 4.5t/gh). In respect of cropping periods, the crop during fall period (February-May) gave higher fruit yield (6.8t/gh) than that during summer period (4.2t/gh). Thus the results indicated that cooling of root-zone temperature through nutrient solution is essential during high temperatures of summer (June-August) in Oman.***

Keywords--- Root-zone, temperature, growth, yield, hydroponics, cucumber

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1. INTRODUCTION

Hydroponics and soilless systems has been widely used for greenhouse cultivation of vegetable crops like cucumber, tomato, sweet pepper etc. across the world including Arabian Peninsula countries under the conditions of water stress [1-2]. Growth and development of the crop plants under hydroponics are influenced by various environmental factors like light and temperature. The air temperature is one of the most important environmental factors for the alternation of plant secondary metabolite production [3-5]. The temperature at the root-zone also influences the growth and chemical composition of many plants [6-10]. One of the characteristics of hydroponic cultivation is the ability to control the temperature of the nutrient solution using heaters or cooling spiral, to increase or decrease the temperature, respectively. Relatively small changes in temperature of the root environment can cause significant impact on the root development depending on phenological stage and duration of temperature [11]. Thus, the control of temperature of the nutrient solution could be a viable alternative in relation to the control of the entire protected environment. In a study with cucumber, it was reported that a combination of 15°C root temperature and 15°C air temperature prohibited growth while 30°C root temperature gave a slight increase in growth for cucumber plant maintained at 15°C air temperature [12]. However, maximum shoot growth was obtained at 30°C air temperature and 25°C root temperature. The root zone temperature has been shown to influence water and minerals uptake in plants [13-14]. During the midday period in the hot summers in most of the arid countries like Oman, the root-zone temperature of hydroponic systems often exceeds

30°C, which strongly suppresses the physiological process of plant growth and reduces production. In view of the above, this study was designed to investigate the effect of root-zone temperature on the growth and yield of cucumber.

2. MATERIALS AND METHODS

Study area

The experiments were conducted in a cooled greenhouse of dimension 30 m long x 9 m wide at the Directorate General of Agriculture and Livestock Research in Rumais, Barka around 40 km north of capital Muscat during three periods of growing cucumber under hydroponics viz. spring (February-May), summer (June-August) and fall (September-November) during 2016/ 2017.

Microclimate monitoring

Three air temperature and relative humidity sensors (Vaisala HMP60, Campbell scientific, USA) were fixed inside the greenhouse at 10 m from the cooling pad and at 10 m from the opposite door side and in the middle of the greenhouse. Inside solar radiation was monitored by pyranometer (CMP3-L14-PT, Campbell scientific, USA) and was installed under the cover in the middle of the greenhouse. A data logger (CR1000, Campbell scientific, USA) was used to store all air temperature, relative humidity and solar radiation sensors data.

Experiment layout

Sixteen growing channels were installed inside the greenhouse. The size of each channel was 5.3m long x 0.4m wide. The growing channels made of cement blocks of size 10cm wide and 20cm long that represented treatments were spaced 1.2 m apart. The treatments included three root-zone temperatures of cooling nutrient solution viz. RZT1 (22 ± °C), RZT2 (25 ± °C) and RZT3 (28 ± °C) besides the control-uncooled nutrient solution (RZT4) that had root-zone ambient temperature of over 30 ± °C. The experiment was arranged in Randomized Complete Design (RCD) with four replications. Number of plants in each treatment was 40 (20 x2) making total number of 640 plants in the experiment. White plastic mulch (100 micron) was used as insulation between the concrete and polyfoam pots to let drainage water from pots to return smoothly to the feeding tanks. Eight independent feeding tanks (400 liters) equipped with submersible pump (0.5HP Lawara, Italy) were fitted for each treatment. Cooled chiller coils made of cupper 1/2 inch were fixed in each of the six of the eight feeding tanks (the remaining two tanks were for control) equipped with digital temperature sensors (GS3, Decagon Inc., USA) to control and adjust the temperature of the nutrient solution in the feeding tanks. Thirty two GS3 temperature sensors were arranged in such a manner that two GS3 temperature sensors were inserted in two pots at 15 cm depth in each treatment with code numbers from 1 to 32 in four replications and connected to the CR1000 data logger which was set at every thirty minute to record temperature of root zone of the cucumber plants in each treatment.

Irrigation and fertilization

Eight Intelligent hydroponic dosers consist of an LCD monitoring screen and three triple pumps (Autogrow system, New Zealand) were installed to monitor conductivity (EC) and pH of the nutrient solutions automatically by which the plants were fertigated. Seeds of cucumber variety namely; Reema F1 (Trust Seeds) were seeded in 72 hole trays on 11/5/2016, 29/8/2016 and 8/2/2017 and transplanted in polyfoam pots in greenhouse on 24/5/2016, 8/9/2016 and 26/2/2017 soon after third true leaf appeared. Drip irrigation lines with emitter 4 liter/hour fixed in each pot was used to irrigate the plants. Time for irrigation was set at one minute for every five minute starting from 7 am morning up to 6 pm evening during the course of the experiment. Two stock solutions: SS1 containing 3kg Calcium nitrate with iron chelate 50 g diluted in 10 liters of water, SS2 containing 3 kg NPK (12:12:36+TE) with magnesium sulfate 1.5kg diluted in 10 liter of water and SS3 containing 1 liter Nitric acid diluted in 20 liter of water were prepared for each treatment to feed the plants through eight Intelligent hydroponic dosers. At the beginning EC (Electro conductivity) was settled at 2dSm^{-1} and further increased gradually as the plant growth increased up to 2.5 dSm^{-1} at the end of the plant cycle while pH was kept at 5.8 to 6.0 from seedling stage terminal of the crop cycle.

Observation recorded

The observed data that were recorded throughout the experiments were; Plant height (cm), leaf number/plant, leaf area index (cm^2), chlorophyll (SPAD values), fruit number/m^2, yield (kg/plot) (t/gh), shoot fresh weight (g), root fresh weight (g), shoot dry weight (g), root dry weight (g), shoot dry weight (%), root dry weight (%), fruit length (cm), fruit diameter (cm) and total soluble solids (TSS) percentage (%) were determined.

Statistical analysis

Analysis of variance (ANOVA) and multiple comparisons (least significant difference (LSD) were performed using GenStat 12th edition [15].

3. RESULTS AND DISCUSSION

The results presented in Tables 1 to 3 indicated the effects of two statistical parameters viz, period, temperature and their interaction were found to be significant ($p<0.05$) in respect of plant height, leaf area, fruit number and shoot dry weight whereas effects of the two variables were only significant ($p<0.05$) for the characters namely leaf number, chlorophyll content, fruit yield and shoot dry weight. However, the effect of only period was found to be significant ($p<0.05$) in respect to both shoot and root dry matter %, fruit length and fruit diameter whereas the effects of period and interaction were significant ($p<0.05$) for only TSS%. Mean air temperature during crop cycle ranged from 25ºC to 32ºC, 29ºC to 34ºC and 25ºC to 30ºC during Feb-May, June-August and September- November of 2016/2017, respectively.

Growth and yield traits

In respect to plant height, the cucumber plants responded significantly ($p<0.05$) higher with plant height of 297.4 cm during June-August (summer) cropping period as compared to that during Feb-May (217.2 cm) and Sept-November (217.2 cm) (Table 1a). Similarly, the cucumber plants responded positively to cooled root-zone temperatures in comparison to uncooled root-zone temperature (control). The plants had insignificantly ($p>0.05$) highest height at RZT-25ºC (255.1 cm) followed that at 22ºC (254.6 cm) and 28ºC (252.4cm). In respect to interaction, plant height was significantly ($p<0.05$) highest at RZT-28ºC during June-August cropping period to that at RZT-22ºC during the same period (314.8 cm) (Table1a). Such effect of interaction between root temperature and period is attributed to different stages of growth of the plants as found in the studies of Moon et al. [16] from the results of which it was observed that during summer the growth rate of the stem at both temperatures had been linear for a long time already whereas in winter it was still exponential while in autumn and spring the growth rate at 25 °C was linear. The authors showed that root-zone cooling did not affect the plant height, number of nodes, and stem weight. Contrarily, it was found that root-zone heating at 33ºC reduced leaf number, shoot length of carrots plants [10]. It was demonstrated that plants of tomato grown at the lowest and the highest root temperatures were fully normal in appearance although their size was smaller than at the optimal temperatures of 20 and 25 °C [17] (Table 1).

In respect to leaf number, the cropping periods of February-May and September-November gave significantly more number of leaves/plant (54) than that during June-August (51) (Table 1a). It was reported that the seasonal effect on leaf number of tomato is much smaller as compared to that on plant height. In their study, at a root temperature of 25°C and 25 days after transplanting e.g., plant height was 42.5 cm in summer and 9 cm in winter while leaf number was only 14.0 in summer 8.3 in winter [18].

Table 1 (a). *Means of plant height, leaf number and leaf area under four RZT and three cropping periods along with statistical parameters in cucumber grown under hydroponics closed-system

	Plant Height (cm)				Leaf Number/plant				Leaf Area (cm^2)			
RZT	Cropping Period			Mean	Cropping Period			Mean	Cropping Period			Mean
	Feb-May	Jun-Aug	Sep-Nov		Feb-May	Jun-Aug	Sep-Nov		Feb-May	Jun-Aug	Sep-Nov	
22ºC	224.5	314.8	224.5	254.6	58	51	58	56	372.3	346.9	311.3	343.5
25ºC	241.4	282.7	241.3	255.1	56	50	56	54	372.3	345.9	322.5	346.9
28ºC	207.6	342.0	207.6	252.4	51	54	51	52	336.8	292.0	290.2	306.3
33ºC	195.4	249.8	195.4	213.5	50	48	50	49	323.7	205.1	268.8	265.8
Means	217.2	297.4	217.2		54	51	54		351.3	297.5	298.2	
	F-Test	LSD (5%)			F-Test	LSD(5%)			F-Test	LSD(5%)		
CP	**	16.8			*	2.8			**	19.1		
Temp.	**	19.4			**	3.2			**	22.0		
Int.	**	33.6			NS	-			**	38.2		
CV	9.4				7.4				8.4			

*RZT-Root Zone Temperature; CP-Cropping period; Temp.-Temperature; Int.-Interaction

Table 1(b). *Means of chlorophyll content (SPAD), fruit number and fruit yield (t/gh) under four RZT and three cropping periods along with statistical parameters in cucumber grown under hydroponics closed-system

	Chlorophyll (SPAD)				Fruit Number/m2				Yield (t /greenhouse*)			
RZT	Cropping Period			Mean	Cropping Period			Mean	Cropping Period			Mean
	Feb-May	Jun-Aug	Sep-Nov		Feb-May	Jun-Aug	Sep-Nov		Feb-May	Jun-Aug	Sep-Nov	
22ºC	47.1	45.3	49.7	47.4	241	180	201	207	7.7	5.0	6.4	6.4
25ºC	47.4	48.0	50.4	48.6	253	167	209	209	8.0	4.4	7.0	6.4
28ºC	42.9	43.0	45.1	43.7	196	178	184	186	5.8	4.7	6.0	5.5
33ºC	43.9	44.3	45.4	44.5	197	101	156	151	5.6	2.8	5.0	4.5
Means	45.3	45.1	47.6		222	156	187		6.8	4.2	6.1	
	F-Test	LSD(5%)			F-Test	LSD(5%)			F-Test	LSD(5%)		
CP	**	0.96			**	17.2			**	0.57		
Temp.	**	1.11			**	19.9			**	0.66		
Int.	NS	-			**	34.5			NS	-		
CV	2.9				12.8				14.0			

*RZT-Root Zone Temperature; CP-Cropping period; Temp.-Temperature; Int.-Interaction; Greenhouse Area-30m x 9m=270 m^2)

No apparent interaction between period and root temperature was observed with leaf number as was the case with plant height since leaf number increased linearly with time. In the present study, effect of RZT on number of leaf /plant was significant and highest at RZT-22ºC (56) followed insignificantly by that at 25ºC (54). These RZTs, however, showed significantly higher leaf number than uncooled RZT (control) 33ºC (49). These results were in agreement with Sakamoto and Suzuki [10] who found that root-zone heating at 33ºC reduced leaf number and shoot length of carrots plants. Similarly, Moon *et al.* [16] revealed that leaves and stem height had slow growth rate as root-zone temperature increased after 7 and 14 days of planting. Further, plant height, leaf number, leaf area were all significantly reduced in the study of tomato on influence of rhizosphere temperature on growth, development and physiological metabolism of greenhouse tomato in summer [19] (Table 1a).

In respect to leaf area, February-May cropping period, which falls in severe winter during February produced significantly highest leaf area of 351.3 cm^2 in comparison with other two cropping periods (Table 1a). Similarly, Denise et al. [20] indicated the superiority of the winter period in terms of leaf area index which at the end of the cycle was 3.74, being 3.0% higher than the autumn period. In Iran, it was revealed leaf area varying from 265.8 cm^2 to 346.9 cm^2 across root-zone temperatures (RZT) [21]. In the present study, cooled RZT of 25ºC and 22ºC gave high leaf area of 346.9 and 343.5 cm^2 respectively as compared to uncooled RTZ (control) 33ºC (Table 1a). Qiu-yan et al. [22] reported that strong interactions were observed between RZT and nutrients on leaf area and concluded that higher biomass and growth of cucumber seedlings were produced at RZT of 20°C. Hye *et al* [23] indicated that leaves of cucumber at 35ºC root-zone temperature (RZT) had severely smaller leaf area whereas the differences in leaf morphologies were reflected by the higher leaf areas from plants grown at root-zone temperature of 30°C as opposed to 15.6°C [24].

Color pigmentation in plants, especially chlorophyll is important for their growth and yield. Hence, leaf color, as faction of chlorophyll content could be used as indication of nutrient status in the plants. In the present study, SPAD values recorded for chlorophyll were used to indicate the effect of root-zone temperatures on cucumber plants and their interactions. The SPAD values varied from 45.1 to 47.6 and from 43.7 to 48.6 for periods and root-zone temperatures (RZT), respectively (Table 1b). Many studies revealed that high temperatures could affect physiology process such as chlorophyll content and metabolism of plant. Heat stress causes an imbalance in plant metabolism and disruption of cellular homeostasis, resulting in deleterious damage to plant cells [25]. Further, Heat stress to the roots was also also found to trigger significant alternations in plant physiological processes such as water uptake and leaf photosynthesis [25- 26]. whereas Masaru et al. [27]observed that the high root-zone temperature treatment induced plant withering within 2 months or decreased the chlorophyll content as expressed by the SPAD value. The results of present study were in agreement with previous above findings. The chlorophyll content in terms of SPAD was found to significantly higher at RZT-25 ºC and RZT-22ºC to the extent of 48.6 and 47.4, respectively compared those at RZT-28ºC and 33ºC- RZT with SPAD values of 43.7 and 44.5, respectively (Table 1b). This could be explained by higher content of chlorophyll which is positively associated with the nutrient uptake status of the plants and photosynthesis rate at 22ºC and 25ºC. Masaru et al. [27] reported that the number of leaves and SPAD value tended to get increased by root-zone cooling while the SPAD values of the surviving plants from the high root-zone temperature treatment were decreased after four months. In respect of effect of cropping periods, the amount of chlorophyll content in the leaves as expressed by SPAD values were significantly ($p<0.05$) higher in September-November (47.6) as compared to those in other two cropping periods (Table 1b). Youssef et al. [28] found no significant effects of interaction between periods and the root-zone temperature (RZT) in chlorophyll contents.
In respect to fruit number, cucumber plants of cooled RZT- 22ºC and 25ºC produced more fruit number/ m^2 to the extent of 207 and 209 respectively that those at RZT-28ºC (186) and control (151) (Table 1b). The results of present study were in agreement with those of Moon et al.[29] who reported that the number of fruits per plant to be 15.9 in non-cooled root-zone while it was 19.3 in cooled root-zone. In respect of cropping periods, February-May produced high number of fruits (222/m^2) followed by September-November which gave 187/m^2 and the lowest was given by June-August (156/$m^{2)}$ (Table 1b). Moon et al. [29] revealed that severe growth and development inhibition by high temperature in summer were observed in cucumber. With regard to interactions effect, Feb-May and September-November and root-zone temperature at 22ºC and 25ºC produced higher number of fruits/m^2 as compared to June-August (Table 1b). High temperature in greenhouse during summer inhibits crop growing especially at RZT that was accompanied with high environmental temperature [30].

It is a fact that environmental stress would affect growth, development and yield of any crop. RZT is the important factor that can effect plant growth and yield through uptake of water and nutrient [31-33]. In the present study significant ($p<0.05$) differences were obtained in fruit yield between the cropping periods and root-zone temperatures (RZT) among the treatments with no significant interactions (Table 1b). With respect to cropping periods, fruit yield ranged from 4.2 t/gh to 6.8 t/gh. February-May period produced the significantly highest yield of 6.8t/gh followed by September-November (6.1 t/gh) whereas lowest yield was obtained during June-August (4.2t/gh) (Table 1b). Low yield in summer was attributed to high air temperatures (PACA,2016) during this period of the year in Oman and other Arabian Peninsula and other arid countries. Severe growth and development inhibition by high temperature in summer have been recorded from cucumber by many authors, for instance, reported higher yields of cucumber during both March to June and September to November as compared those in during summer period, especially in July and August in Korea [34]. Similarly, Lee [35] and Du and Tachibana [36-37] revealed that high temperature in summer and low temperature in winter are one of the main factors in reducing productivity in the year-round cultivation of cucumber. Further, they observed that below 12-13 ºC RZT, growth was suspended and over 35 ºC RZT, growth was found inhibited. With regard to RZT, fruit yield varied from 4.5t/gh to 6.4t/gh between the treatments. Cucumber produced higher yields of 6.4t/gh 6.4t/gh and 5.5t/gh, respectively, at RZT 22ºC, 25ºC and 28ºC of the cooled root-zone as compared to uncooled root-zone temperature of control 33ºC (4.5t/gh) (Table 1b). These results were in in agreement with Moon et al. [29] who found that most remarkable effect of root-zone cooling was the increase of the yield in cucumber as compared to cucumber grown in non-cooled root-zone. Similarly, Lee [35] reported that as the plants grew, the yield of cucumber fruits proportionally decreased with increased root-zone temperature. In the case of tomato also, when the root-zone temperature was cooled to 25°C under high air temperatures, vegetative growth was improved by increasing leaf area and plant height as compared with uncooled plants at root zone, and fruit yield was found increased [38-40]. Although interactions did not significantly affect the fruit yield of cucumber in the present study, it was numerically higher at all RZTs in all three cropping periods as compared to uncooled RZT-33ºC (control). These findings suggested that cooled of root-zone of cucumber through cooled nutrient solution temperature especially during summer periods result in increased yield of cucumber (Table 1b).

Weight related traits on a plant basis

In respect to effect of cropping periods, the crop grown during September- November gave significantly ($p<0.05$) more shoot fresh weight (314.5 g/plant) than that of June-August period (237.1 g/plant) and it was insignificantly different to the crop of February-May (305.0 g/plant) (Table 2a). In respect of effect of RZT, the crop with 25ºC gave significant highest shoot fresh weight (365.4 g/plant) to that of RZT- 22ºC (302.4 g/plant) and the lowest was given by control (RZT- 33ºC) (242.6 g/plant) (table 2a). Daskalaki and Burrage [41] found that shoot fresh weight was highest at 28ºC and lowest at 12ºC. Adebooye et al. [42] found significantly ($P \leq 0.05$) higher number of tendrils, number of leaves, fresh leaf weight, stem length, fresh stem weight, root length, root weight and root volume at 30ºC as compared to 20ºC and 25ºC in tomato crop. In another study with muskmelon, it was reported that plant fresh weight gain for large plants was highest at the RZT- 25°C whereas for small plants fresh weight gain was similar from 25 to 35°C [43]. Jin Sun et al. [44] reported that RZ cooling increased plant shoot fresh weight, root fresh weight, shoot dry weight, root dry weight, total plant fresh weight, and total plant dry weight by 8.9, 20.5, 7.8, 14.3, 9.7, and 8.5%, respectively in Lettuce.

Table 2(a). *Means of shoot fresh weight (g), shoot dry weight (g) and shoot dry matter (%) under four RZT and three cropping periods along with statistical parameters in cucumber grown under hydroponics closed-system

	Shoot fresh weight (g)				Shoot dry weight (g)				Shoot Dry matter (%)			
RZT	Cropping Period			Mean	Cropping Period			Mean	Cropping Period			Mean
	Feb-May	Jun-Aug	Sep-Nov		Feb-May	Jun-Aug	Sep-Nov		Feb-May	Jun-Aug	Sep-Nov	
22ºC	321.2	264.1	321.8	302.4	55.0	48.7	52.5	52.1	17.1	18.7	16.3	17.4
25ºC	358.6	274.2	365.4	332.7	59.4	49.3	56.7	55.1	16.7	18.5	15.7	17.0
28ºC	281.1	222.0	290.4	264.5	39.5	39.8	44.5	41.3	14.1	18.2	15.5	15.9
33ºC	259.2	188.2	280.5	242.6	44.7	37.1	42.8	45.5	17.2	20.1	15.4	17.6
Means	305.0	237.1	314.5		49.6	43.7	49.1		16.3	18.9	15.7	
	F-Test	LSD(5%)			F-Test	LSD(5%)			F-Test	LSD(5%)		
CP	**	12.5			**	2.4			**	1.6		
Temp.	**	14.4			**	2.8			NS	-		
Int.	NS	-			**	4.8			NS	-		
CV	12.4				7.0				13.2			

*RZT-Root Zone Temperature; CP-Cropping period; Temp.-Temperature; Int.-Interaction

Table 2(b). * Means of root fresh weight (g), root dry weight and root dry matter (%) under four RZT and three cropping periods along with statistical parameters in cucumber grown under hydroponics closed-system

	Root fresh weight (g)				Root dry weight (g)				Root dry matter (%)			
RZT	Cropping Period			Mean	Cropping Period			Mean	Cropping Period			Mean
	Feb-May	Jun-Aug	Sep-Nov		Feb-May	Jun-Aug	Sep-Nov		Feb-May	Jun-Aug	Sep-Nov	
22ºC	45.0	38.0	41.9	41.6	21.1	20.2	21.2	20.8	47.4	53.7	51.2	50.8
25ºC	45.2	36.0	39.6	40.3	20.8	20.0	21.0	20.6	46.5	56.2	53.7	52.2
28ºC	38.2	34.8	34.9	36.0	18.0	17.6	18.3	18.3	48.0	51.5	53.0	50.9
33ºC	34.2	28.9	31.0	31.4	17.6	16.6	17.2	17.2	51.5	57.8	55.8	55.1
Means	40.6	34.4	36.8		19.4	18.6	19.4		48.4	54.8	53.5	
	F-Test	LSD(5%)			F-Test	LSD(5%)			F-Test	LSD(5%)		
CP	**	3.4			**	0.56			**	4.5		
Temp.	**	3.9			**	0.65			NS	-		
Int.	NS	-			NS	-			NS	-		
CV	12.6				4.1					12.1		

*RZT-Root Zone Temperature; CP-Cropping period; Temp.-Temperature; Int.-Interaction

Shoot dry weight varied from 43.7g to 49.6g and from 41.3g to 55.1g for periods and RZTs, respectively with significant ($p<0.05$) effects. The crops of February-May period (49.6g) and September-November period (49.1g) were significantly highest ($p<0.05$) to that of June-August period which was the lowest (43.7 g). In respect of RZT, cooled RZT- 25°C gave significantly the highest shoot dry weight (55.1 g) to the cooled RZT- 22°C (52.1 g). However, the shoot dry weight at RZT-28°C (41.3 g) and RZT-33°C (control; 45.5 g) were significantly low. The result obtained by different researchers (9-10, 45) also showed that RZT influences the vegetative growth and biomass of the plant. Accordingly, the results of the present study are in agreement with James. A. et al. [46] who reported that root and shoot dry weight, rate of shoot growth, plant height, and water use peaked at 25°C, which was considered as optimal temperature. Significant ($p<0.05$) differences were revealed in interactions as the crops of the periods February-May and September-November gave the higher shoot dry weights (g) at cooled RZT at 25°C and 22°C. In lettuce growth was remarkably improved by RZ Cooling and that it was feasible in cultivating hydroponic lettuce in a high-temperature period through cooling of the nutrient solution [44]. The results of the present study also demonstrated that the growth of cucumber can be promoted by cooling of root-zone temperature through cooling of nutrient solution temperature during summer (June –August) period (Table 2a).
In respect of root fresh weight, it was significantly highest ($p<0.05$) in the crop of Feb-May (40.6 g) to that of both June-August (34.4 g) and September- November (36.8). (Table 2b). With respect to RZT, the crops at RZTs 22°C and 25°C gave significantly highest root fresh weights of 41.6 g/plant and 40.3 g/plant to that of RZT -28°C (36.0g/plant) and RZT- 33°C (31.4 g/plant) (Table 2b). In another study shoot fresh weight was highest at 28°C and lowest at 12°C [42]. Root zone temperatures (T) caused statistically significant ($p \leq 0.05$) positive effects on the average number of tendrils, number of leaves, fresh leaf weight, stem length, fresh stem weight, root length, fresh root weight and root volume and they were parameters were highest at 30°C as compared to 20°C and 25°C in tomato crop [41]. It was reported that RZ cooling increased plant shoot fresh weight, root fresh weight, shoot dry weight, root dry weight, total plant fresh weight, and total plant dry weights by 8.9, 20.5, 7.8, 14.3, 9.7, and 8.5%, in lettuce respectively [44]. Significant ($p<0.05$) effects of root-zone cooling were observed in root dry weight between the treatments (Table 2b) as those of cropping periods ($p<0.05$) in the present study. Root dry weight varied from 18.6g to 19.4g. February-May and September-November gave the highest root dry weights (19.4g) while the lowest was found with June-August (18.6 g) (Table 2b). These results were in agreement with findings of Schmidt et al. [47] who reported that at the end of the cycle, the root dry mass accumulation of lettuce was 68.72 g/ m^2 and 46.76 g/m^2 for the autumn and winter periods, respectively. The superiority of the autumn period was possibly related to the temperature of the nutrient solution and the environment inside the growing profile, which was lower during the autumn period. Jin Sun *et al.* (2016) showed that lettuce growth was remarkably improved by RZ Cooling. With regard to root-zone cooling effects, the crops with root-zone at temperatures 22°C and 25°C gave significantly the highest root dry weights of 20.8g and 20.6g, respectively to RZT- 28°C (18.3g) and RZT- 33°C (control; 17.2g) (Table 2b). Similar results were obtained in earlier studies [9-10, 45] James et al. [46] reported that root and shoot dry weight, rate of shoot growth, plant height, and water use peaked at 25°C and that optimal temperature was found to be approximately 25°C

The values of dry matter % were significant only for cropping periods ($p<0.05$). Accordingly, shoot and root dry matter percentages (%) were significantly ($p<0.05$) higher in summer period (June-August) (18.9 % & 54.8%) than those in February-May (16.3 % and 48.4 %). However, with respect to root-zone temperatures, shoot and root had the insignificantly the highest dry matter percentages at RZT 33°C (control) (17.6 % and 55.1%) as compared to those at RZTs of 22°C, 25°C and 28°C (Tables 2 a and b). These results are in agreement with Masaru and Takahiro [48] who observed that despite the absence of significant differences between RZTs, the shoot and root dry matter % under low root-zone temperature treatment tended to be lower than those of the plants under ambient root-zone temperature treatment. However, Jin Sun et al. (2016) showed that root zone cooling increased plant shoot and root weights besides their dry matter %.

Quality attributes
In respect to quality traits of cucumber, fruit length varied from 14.3 cm to 16.5cm and from 15.4cm to15.5 cm for the cropping periods and root-zone temperature respectively with significant ($p<0.05$) differences only between the periods (Table 3). The crop of Feb-May period gave highest fruit length of 16.5cm whereas the lowest was observed in the crop of September-November period (14.3cm). Similarly, with regard to fruit diameter, significantly differences were observed only between the periods. The crop of September-November gave highest fruit diameter (3.3 cm) whereas that of June-August period was the lowest (3.1cm). In general, the crops with RZT 22°C and 25°C had the higher fruit length (15.5 cm) and diameter (3.3 cm).

Table 3. *Means of fruit length, fruit diameter and total soluble solids (TSS % as *brix*) under four RZT and three cropping periods along with statistical parameters in cucumber grown under hydroponics closed-system

	Fruit length (cm)				Fruit diameter (cm)				Total soluble solids (%)			
RZT	Cropping Period			Mean	Cropping Period			Mean	Cropping Period			Mean
	Feb-May	Jun-Aug	Sep-Nov		Feb-May	Jun-Aug	Sep-Nov		Feb-May	Jun-Aug	Sep-Nov	
22ºC	16.5	15.5	14.3	15.4	3.4	3.2	3.3	3.3	3.8	2.5	3.7	3.3
25ºC	16.8	15.2	14.5	15.5	3.5	3.1	3.4	3.3	3.6	2.9	3.6	3.3
28ºC	16.6	15.3	14.3	15.4	3.2	3.1	3.3	3.2	3.6	2.6	3.5	3.2
33ºC	16.2	16.1	14.2	15.5	3.4	3.0	3.3	3.2	3.9	2.4	4.0	3.4
Means	16.5	15.5	14.3		3.3	3.1	3.3		3.7	2.6	3.7	
	F-Test	LSD (5%)			F-Test	LSD (5%)			F-Test	LSD (5%)		
CP	**	0.46			**	0.13			**	0.19		
Temp.	NS	-			NS	-			NS	-		
Int.	NS	-			NS	-			**	0.39		
CV	4.1				5.6				8.1			

*RZT-Root Zone Temperature; CP-Cropping period; Temp.-Temperature; Int.-Interaction

The results indicated significant ($p<0.05$) differences in TSS (total soluble solids percentage as brix) of cucumber fruits between periods. The TSS was also affected significantly by the interactions ($p<0.05$). February-May and September-November gave the highest TSS (3.7%). The crops of September- November and February-May had the higher TSS of 4.0 and 3.9, respectively at RZT of 33^{o}C. Mohamed [49] indicated that TSS did not differ between the two cucumber cultivars in two growing periods studied. Similar to the present study, Peyvast et al [50] found no significant effects on RZTs in total soluble solids percentage in cucumber fruits. The results of the present study indicated that root-zone temperatures did not affect the quality of cucumber fruits, as this could be associated with other physiological factors, nutrient uptake of cucumber in different periods.

4. CONCLUSION

The results of the present study showed that RZTs of 22^{o}C and 25^{o}C were effectives in all characters tested for cucumber in all the three cropping periods studied. However, the present experiment aimed at comprehending cucumber's response for summer period in which production of cucumber would be affected by very high temperatures coupled with occurrence of Phythium disease. The findings indicated that cooling of root-zones of cucumber through cooled nutrient solution during summer periods would result in increased yield of cucumber.

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