J. Agr. Sci. Tech. (2015) Vol. 17: 691-704

Fruit Quality and Yield of Tomato as Influenced by Rain Shelters and Deficit Irrigation

G. C. Shao[1*], S. Deng [1], N. Liu[2], M. H. Wang [1], and D. L. She [1]

ABSTRACT

This study was conducted to determine the effects of the combined use of rain shelters (RS) and deficit irrigation (DI) on tomato yield and quality characteristics. Two experiments with different treatments were conducted in the southern China during the growing season in 2011 and 2012. The crops were irrigated to field capacity once average soil water content at the 0-60 cm layer in the treatment decreased to 80% of field capacity under open-field (T1, the control) and RS (T2), and 30, 40, and 50% decreased water of T2 as treatments T3, T4, and T5, respectively. The results showed that T2 increased the yield and irrigation water use efficiency (IWUE) by 13 and 11.5% in the two years, and improved fruit firmness (FF), total soluble solids (TSS), soluble sugar (SS), and vitamin C (VC) compared to T1. Under RS conditions, DI reduced the yield, but increased IWUE of tomato relative to T2 from 25 to 52% in 2011, and from 26 to 41% in 2012. The effects of DI on fruit quality were generally the inverse of those on fruit yield. FF, TSS, SS, VC, organic acid, and color index were positively affected by DI. With regard to the rank of comprehensive quality index (CQI) calculated by the analysis hierarchy process and modified technique for order preference by similarity to an ideal solution, it exhibited good fitness to the rank of single quality attributes. The highest CQI was obtained in treatment T4 in 2011, and T3 in 2012.

Keywords: Deficit irrigation, Quality characteristics, Rain shelters, Tomato, Yield.

INTRODUCTION

Tomato (*Solanum lycopersicum* L., syn. *Lycopersicon esculentum* Mill.) is one of the popular horticultural crops and it is an important source of antioxidants such as lycopene, phenolics, and vitamin C (VC) in human diet (Toor *et al*., 2006). The yield and quality of fresh tomato are affected by both genetic factor and growing condition (Viskelis *et al*., 2008). The current climate in southern China is characterized by a predominance of summer precipitation with dry winter and variable spring precipitation. Besides heat, insect pests, and diseases, a major constraint for the production of tomato in this region is the abundance of rainfall, particularly in combination with shallow ground water. Heavy rain, high temperature, and high levels of relative humidity–typical attributes of subtropical or tropical climates- have been reported to increase the incidence of blossomed rot (Ho and White, 2005) as well as fruit cracking (Peet, 1992) and impair fruit quality and yield. Precipitations have been linked to reductions in small fruit yield and shelf-life due to rain-driven epidemics of phytopathogens (Xiao *et al*., 2001).

[1] Key Laboratory of Efficient Irrigation-Drainage and Agricultural Soil-Water Environment in Southern China, Ministry of Education, College of Water Conservancy and Hydropower Engineering, Hohai University, Nanjing 210098, Peoples' Republic of China.

[*] Corresponding author; email: sgcln@126.com

[2] School of Economics and Management, Nanjing University of Information Science & Technology , Nanjing 210044, Peoples' Republic of China.

As the market for fresh vegetable is growing steadily, the need for higher quality is increasing (Ruiz-Altisent *et al*., 2006). Among the environmental factors, water is one of the important factors affecting fruit quality of tomato, therefore, irrigation and drainage management strategies are critical to increase tomato yield and quality in southern China. Deficit irrigation, where only a portion of evapotranspiration is given to plants over the entire root system, has been studied for tomato with mixed results. Pulupol *et al*. (1996) observed that deficit irrigation caused a significant reduction in dry mass yield for a glasshouse cultivar, while other studies reported no reduction for a field-grown processing cultivar. Appropriate deficit irrigation can lower color hue angle, increases contents of vitamin C, fruit redness, beta-carotenoid, and lycopene in processing tomato (Patane and Cosentino, 2010). Johnstone *et al*. (2005) showed that deficit irrigation at early fruit ripening stage could effectively increase total soluble solids (TSS) of processing tomato. Liu and Chen (2002) showed that after the first three trusses fruit set, reducing proper irrigation times increased the contents of soluble solid content, titration acidity, VC, and soluble solid/acid ratio of cherry tomato and also improved water use efficiency. However, the mentioned studies were mostly conducted in the water shortage region, and only investigated the relationship between single quality attributes and water condition at different growth stages. The relationships are difficult to set down an efficient irrigation scheduling for the compromise between yield and quality in tomato. It is necessary to put forward a new method to determine the comprehensive quality index and study its response to different irrigation managements.

Alleviation of the adverse effects of the abundance of rainfall on tomato yield and fruit quality is, therefore, a prerequisite for sustainable tomato production in southern China. Cover cropping techniques such as polyethylene rain shelters cultivation, which can provide protection against heavy rain, reduce disease pressure and running cost and, therefore, increase crop yield and productivity have been introduced in the area. To our knowledge, there have been fewer experiments studying the effect of rain shelters combined with deficit irrigation on fruit yield and qualitative characteristics. For tomatoes grown in rain shelters, the growth periods and micro-climates were significantly different from open-field conditions. It is necessary to investigate the yield and quality response of tomato to water stress under rain-shelter cultivation. The aim of this work was to study the effects of rain shelters and deficit irrigation on tomato yield and fruit quality attributes in a subtropical climate in China.

MATERIALS AND METHODS

Experimental Site and Plant Material

The experiments were conducted at the Key Laboratory of Efficient Irrigation-Drainage and Agricultural Soil-Water Environment in Southern China, Ministry of Education (latitude 31°57' N, longitude 118°50' E, 144 m above sea level) during the tomato growing season (March to September) of 2011, and repeated in 2012 (Figure 1). The site is in a typical subtropical temperate climate zone with annual precipitation of 1,072.9 mm and pan evaporation of 1,472.5 mm. The experimental field is 18 m long and 7.8 m wide with planting area of 140 m^2. The mean dry bulk density and soil volumetric water content at field capacity and wilting point was 1.35 g cm^{-3}, 0.34 and 0.24 cm^3 cm^{-3} for the upper 0–30 cm soil layer. The soil type was clay loam with a pH of 6.1 and 0.72% of organic matter content. Tomato (Xi Lan in 2011 and Asian Fengwang in 2012) seedlings of open-field cultivar were raised in a nursery and transplanted on 12 April 2011 (April 13 2012). A week before transplanting, the experimental site was ploughed and harrowed to depths of 25 cm.

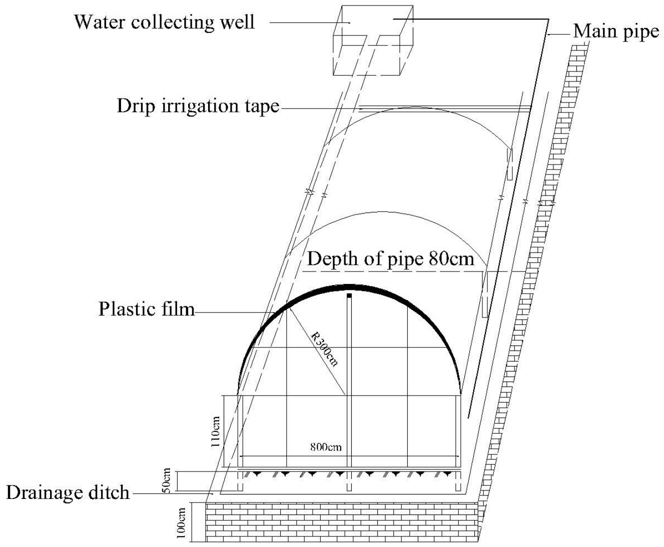

Figure 1. Sketch of experimental plot under rain-shelter.

In all treatments, fertilizers (15:15:15) at the rate of 1,200 kg ha^{-1} were applied and incorporated into soil. All the crops were irrigated and allowed to drain to field capacity. After 24 hours, the seedlings were transplanted into 15 plots. Each plot consisted of three rows of 2 m in length, among which plants were grown 50 cm apart with 40 cm spacing in each row. Only the central row was harvested for production measurements. It was followed by a light irrigation to ensure seedling establishment. The treatments were imposed two weeks after transplanting. Calcium Ammonium Nitrate (26% N) fertilizer was applied as side dressing at the rate of 250 kg ha^{-1} in two equal split doses at 5th and 7th week after transplanting when the plants were at flowering and first fruit set stages, respectively. The plots were manually weeded three times in the season. The plants were sprayed against fruit worms and other pests with insectpowder at the rate of 0.8 l ha^{-1} at the 6th week after transplanting.

Treatments and Experimental Design

Five treatments replicated three times were applied to the experimental units (Table. 1). Seven days after transplanting, tomato crops were irrigated to field capacity when average soil volumetric water content at the 0-60 cm layer in CK treatment (full

Table 1. Experiment design of tomato for different treatments in 2011 and 2012 seasons.[a]

Treatment	Description
T1 [b]	Irrigation lower limit is 80% of field capacity, No rain shelters and drainage measure
T2	Irrigation lower limit is 80% of field capacity, Rain shelters measure
T3	Compared to T2:70% water was applied at the irrigation time of T2, Rain shelters measure
T4	Compared to T2:60% water was applied at the irrigation time of T2, Rain shelters measure
T5	Compared to T2:50% water was applied at the irrigation time of T2, Rain shelters measure

[a] Irrigation method is drip irrigation. The depth of drainage pipe for all the treatments is 0.8 m.
[b] Is taken as control

irrigation) decreased to 80% of field capacity. Tomato crops were drip-irrigated and the irrigation amount was recorded using a magnetic flowmeter. To avoid the influence of groundwater on crop, drainage pipe for all the treatments was installed at the depth of 0.8 m.

Soil Moisture Content and Crop Water Consumption

Air temperature and relative humidity were monitored with dataloggers. The soil water content was measured and controlled with the time domain reflectometry (TDR) and by the microwave drying method. Soil-water-content profiles data was used to adjust irrigation schedule to ensure that the envisaged irrigation treatments could indeed be realized. The tensiometers were placed at the first and second treatment at uniform depths of 60 cm below the soil surface. The tensiometer readings were recorded daily and irrigation was applied when soil moisture reached 80% of field capacity in the designated plot.

Measurements of Yield, Quality and Water Use Efficiency

Individual fruit weight and fresh yield of tomato were measured at each harvesting time. In order to avoid border effects, only the 5 plants in the middle part of each plot were used for the yield and subsequent quality measurements. Irrigation water use efficiency (IWUE) was calculated by dividing amount of water used for irrigation by total fresh yield (Wang *et al*., 2011).

Ripened fruits of the first and the second trusses were sampled at harvest for laboratory analyses (AOAC, 1990). The tomatoes were washed with running water to remove dirt and were dried thoroughly with absorbent paper. Then, they were analyzed for single fresh fruit weight (g). Fruit diameters in the horizontal and vertical direction were measured using a Vernier caliper, and shape index was calculated using the ratio of vertical to horizontal diameters. Fruit color was measured with a spectrophotometer (SP60, Xrite, and Incorporated, MI, USA). Three readings of CIE (Commission International d'Eclairage) color space coordinates *L, a*, and *b* values were obtained from four fruit equatorial orientation, and then average values were converted to color index (Intelmann *et al*., 2005).

Fruit firmness (kg cm^{-2}) was detected using a fruit firmness tester (FHR-5, Takemura electric works, Ltd., Japan) at harvest. Measurements were done on the fruit shoulder 1.5 cm from blossom scar using a cylindrical probe (5 mm diameter). TSS of tomato juice were measured with a digital refractometer ACT-1E produced by TAGO in Japan at 20°C. The refractometer was washed with distilled water each time after use and dried with blotting paper. VC (ascorbic acid) was determined by titration of homogenate tomato samples (diluted in a 3% meta-phosphoric acid solution and an 8% acetic acid solution) using a 2, 6-dichlorophenol-indophenol solution standardized in a solution of ascorbic acid with a known concentration. Total soluble sugar content was measured using anthrone method (Spiro, 1966). Sugar-acid ratio was calculated equivalents of total soluble sugar expressed as percentage of total acidity (Citric acid). Organic acid was titrated with 0.1 mol·L^{-1} NaOH and calculated as equivalents of citric acid expressed as percentage of fresh mass (AOAC, 1990). There were totally 6 measurements in the 2011 and 2012 seasons and the average values were for single quality attributes.

Statistical Analysis

All statistical analyses were performed using SAS software Version 9.2 (SAS Institute, Cary, NC, USA). Analysis of variance (ANOVA) was performed using the GLM procedure and multiple comparisons of mean values were performed using least significant difference (LSD) test at $P_{0.05}$ level. The matrix calculation was done with Matlab 7.0.4 (The Math works Inc.).

RESULTS

Response of Single Quality Attributes of Tomato to Different Treatments

Fruit water content and fruit firmness are the main attributes which determine storage quality of tomato (Dorais *et al*., 2001; Viskelis *et al*., 2008). In the 2011 season, only the T5 treatment significantly decreased the fruit water content when compared to T1, while other treatments were not significantly lower (Figure 2-A). Rain shelters did not significantly affect fruit water content in either year. In the 2012 season, fruit water content of T4 and T5 was significantly lower than that of T1. With respect to fruit firmness, T3, T4, and T5 significantly increased fruit firmness in both seasons when compared to T1, which means that they can stand tougher mechanical damage and, thus, have loner storage duration than that of T1 (Figure 2-B). In both seasons, no significant difference for the fruit firmness was observed between T2 and T1.

Fruit appearance is the first quality trait to consumers and determined by fruit size,

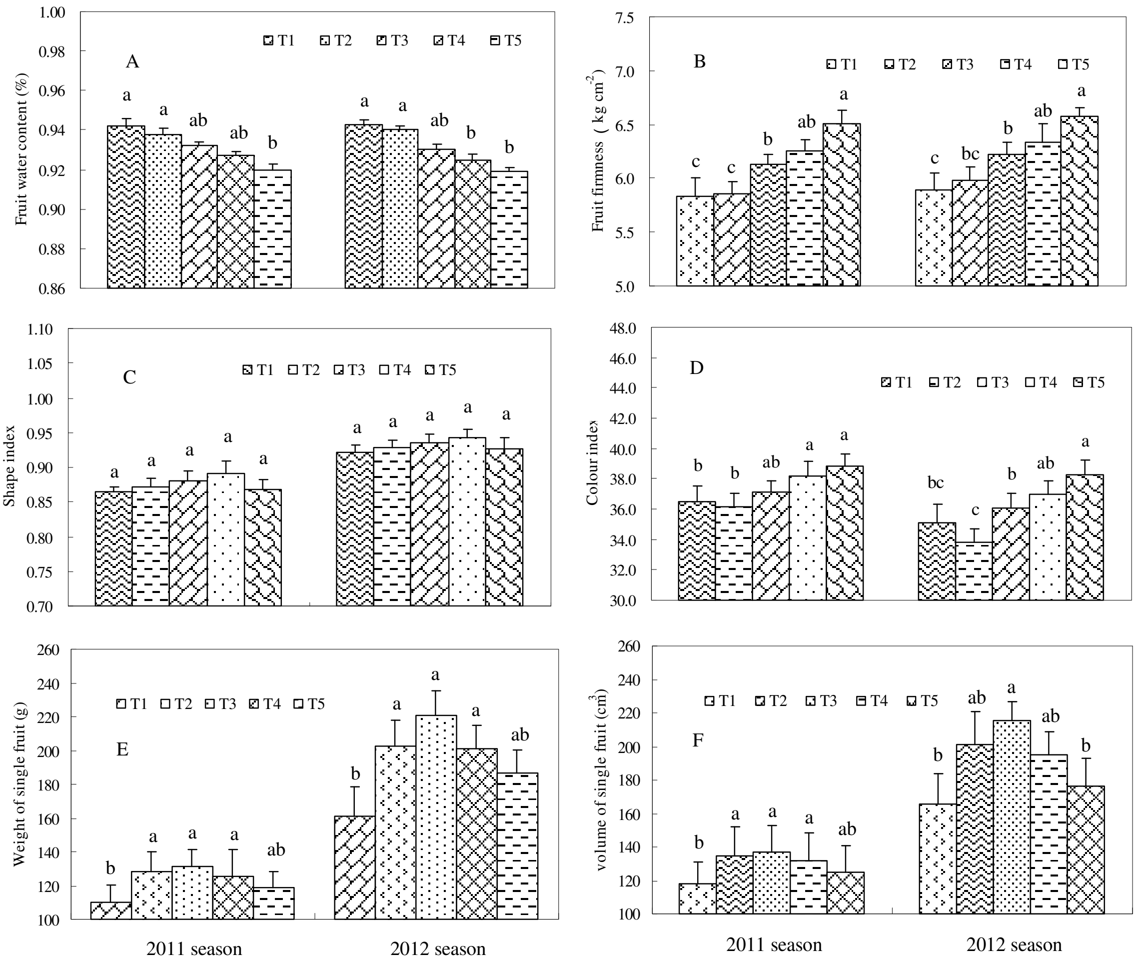

Figure 2. Effects of different irrigation treatments on quality attribute of tomato fruit in the 2011 and 2012 seasons. Columns with the same letter represent values that are not significantly different at the 0.05 level of probability according to the LSD test. Vertical bars represent ±*SE* of the mean. The *SE* was calculated across three replicates for each year. The treatment symbols are the same as in Table 1.

shape, and color (Labate *et al*., 2007). For both seasons, there was no significant difference in the shape index of tomato fruit harvested in different irrigation treatments (Figure 2-C), which implied that the fruit shape was mainly determined by the genetics of the cultivar. In both seasons, open-field tended to have redder fruit color, but there was no significant difference between T1 and T2. When compared to T2, treatments T4 and T5 significantly increased the fruit color index by, respectively, 4.66 and 6.30% in the 2011 season. In the 2012 season, only T5 significantly decreased color index compared with T2 (Figure 2-D). In the 2011 season, Figure 2-E shows that single average fresh fruit weight was not significantly affected by irrigation treatments inside rain shelters compared to T2 in both seasons, but in both seasons, single average fresh fruit weight of T2, T3, and T4 was significantly higher than that of T1, which indicates that rain shelters had significant influence on yield per fruit. In the 2011 season, the volume per fruit of T2, T3, and T4 was significantly higher than that of T1. In the 2012 season, only the T3 treatment had significantly higher volume per fruit as compared to T1 (Figure 2-F).

Tomato taste and nutritional quality are largely determined by the contents of TSS, organic acid, soluble sugar, VC, and their ratio between soluble sugar and organic acid (Dorais *et al*., 2001). Compared to CK, T3 and T5 did not significantly affect organic acid in the first year, but did so in the second year (Table 2). The values of VC increased with less irrigation amount. In the 2011 season, T3, T4, and T5 significantly increased VC by 15.1, 27.7, and 34.9%, respectively. In the 2012 season, T4 and T5 also significantly increased VC by 25.8 and 32.1%, respectively (Table 2). The sugar/acid ratio in T4 and T5 was 26.2 and 29.0% higher than that in T1 in the 2011 season, and 9.9% and 11.7% in the 2012 season, respectively. Compared to T1, T5 significantly increased the organic acid content of fruit by 24.4 and 20.9%, and the sugar/acid ratio by 18.8 and 13.0% in the two seasons, respectively (Table. 2). The sugar/acid ratio did not change much between open cultivation and rain shelters. However, the higher sugar/acid ratio was achieved in fruits under rain shelters.

Comprehensive Quality Index and Its Response to Different Treatments

According to the overall weights obtained from the Analysis Hierarchy Process (AHP),

Table 2 Effects of the combined use of rain shelters and deficit irrigation on taste quality attributes of tomato fruit in 2011 and 2012 seasons.[a]

Cropping season	Treatment	Total soluble solids (%)	Organic acid (g 100 g^{-1})	Vitamin C (mg 100 g^{-1})	Sugar/Acid ratio
2011 season	T1	4.38c	0.72a	10.03c	7.06b
	T2	5.71b	0.71a	11.07bc	7.72b
	T3	6.15ab	0.69a	11.54b	7.96b
	T4	6.21ab	0.54b	12.81ab	8.91ab
	T5	7.96a	0.66a	13.53a	9.11a
2012 season	T1	3.50c	0.48b	11.92b	10.21b
	T2	4.22b	0.53ab	12.53b	10.75ab
	T3	4.75ab	0.57a	14.37ab	10.95ab
	T4	4.94a	0.58a	15.00a	11.22a
	T5	5.40a	0.60a	15.75a	11.40a

[a] Columns with the same letter represent values that are not significantly different at the 0.05 level of probability according to the LSD test. Each value is the mean (n= 3). The treatment symbols are the same as in Table 1.

the calculation steps of modified technique for order preference by similarity to an ideal solution (TOPSIS) method (Deng *et al*., 2000), the comprehensive quality of tomato was calculated, as shown in Table 3 and Table 4. The results showed that exterior was the most important quality, which had the highest criteria weight of 0.411. And the criteria weight of taste, nutrition, and storage quality was 0.296, 0.106, and 0.187, respectively. Among the single quality attributes, the volume of single fruit had the highest overall weight of 0.194, while fruit water content had the lowest overall weight of 0.072 (Table 3). In this study, different treatments had similar ranking for the comprehensive quality index in both seasons. In the 2011 season, T4 and T5 had higher comprehensive quality index, with the values of 0.685 and 0.682, respectively, while T1 had the lowest comprehensive quality index, with the values of 0.011. In the 2012 season, the highest comprehensive quality index was obtained in treatment T3, with the value of 0.657. While T1, T2, and T5 had lower comprehensive quality index, with the values of 0.296, 0.480, and 0.550, respectively.

The Spearman ranking correlation analysis between single quality attributes performance and the comprehensive quality index were used to assess the rationality of comprehensive quality index (Table 4). In the 2011 season, the ranks of color index and fruit water content were negatively correlated with that of the comprehensive quality index. In the 2012 season, including color index and fruit water content, organic acid also negatively correlated with the rank of the comprehensive quality index. While the ranks of the other attributes were positively correlated with that of the comprehensive quality index. The numbers of negative and positive correlation coefficients occupied 23 and 77% of the total in 2011, and 27 and 73% in 2012, respectively. The Spearman correlation coefficient of comprehensive quality index in both seasons was 0.89.

Yield and Water Use Efficiency

Table 5 details the 2011 and 2012 results that relate to fruit yield, irrigation water use efficiency (IWUE) and WUE of tomato. As could be concluded from data, the more water was applied, the higher fruit yield was obtained, while IWUE was decreased with the increase in the amount of irrigation. It is consistent with former research (Sensoy *et al*., 2007). The highest and lowest amounts for yields of 156.43 and 118.57 t ha^{-1} (2011) and 168.39 and 118.50 t ha^{-1} (2012) were obtained in T2 and T5 treatment, respectively. The yield of T2 and T3 were not significantly affected, but T4 and T5 significantly decreased the yield by 8.3 and 14.0% in the 2011 season, and 11.4 and 29.6% in the 2012 season, respectively, when compared to T1. There were no significant differences between T1 and T2, indicating that the fruit yield was not influenced positively by the rain-shelter cultivation. In both season, T3, T4, and T5 significantly decreased the crop water consumption, when compared to T1. With regard to WUE, it ranged from 44.5 to 68.7 kg m^{-3} and 49.3 to 69.4 kg m^{-3} depending on the treatments and experimental years.

DISCUSSION

The critical parameter that has to be considered in a hot and wet environment is the occurrence of heavy rain. Visual observations during the first year of the experiments showed that tomato plants without rain-shelter and drainage looked significantly waterlogging stressed during the periods of rainfall, which could lead to physiological disorders impairing fruit quality and the proportion of marketable yield in tomatoes. A few studies have suggested that rain shelters, through reduced disease pressure, can increase crop yield and productivity (Masaki, 1987; Xiao *et al*., 2001).

In this study, no significant effects of water regime on fruit size under the

[DOR: 20.1001.1.16807073.2015.17.3.4.9]

Table 3. Pair-wise comparison matrix and weights from AHP for the evaluation hierarchy criteria and fruit attributes level.[a]

Level or sub-level of evaluation hierarchy		Pair-wise comparison matrix				Local weight	Overall weight
		Exterior	Taste	Nutrition	Storage		
Criteria level	Exterior	1.00	1.33	4.00	2.22	0.411	
	Taste	0.75	1.00	2.70	1.56	0.296	
	Nutrition	0.25	0.37	1.00	0.56	0.106	
	Storage	0.45	0.64	1.77	1.00	0.187	
λ max= 3.997, CI= -0.001, RI= 0.890, CR=- 0.001							
Level or sub-level of evaluation hierarchy		Pair-wise comparison matrix				Local weight	Overall weight
		Shape index	Weight of single fruit	Volume of single fruit	Color index		
Sub-level of external quality attributes	shape index	1.00	0.50	0.25	0.50	0.108	0.044
	weight per tomato	2.00	1.00	0.33	0.50	0.164	0.067
	volume per	4.00	3.00	1.00	2.00	0.472	0.194
	color index	2.00	2.00	0.50	1.00	0.256	0.105
λ max= 4.043, CI= 0.015, RI= 0.890, CR=0.016							
Level or sub-level of evaluation hierarchy		Pair-wise comparison matrix				Local weight	Overall weight
		Total soluble	Organic acid	Sugar/Acid ratio			
Sub-level of taste quality attributes	total soluble	1.00	0.50	0.95		0.248	0.073
	Organic acid	2.02	1.00	1.79		0.487	0.144
	Sugar/Acid	1.05	0.56	1.00		0.266	0.079
λ max= 3.004, CI= 0.002, RI= 0.520, CR=0.003							
Level or sub-level of evaluation hierarchy		Pair-wise comparison matrix				Local weight	Overall weight
		Vitamin C					
Sub-level of nutritional quality attributes	Vitamin C	1.00				1.000	0.106
Level or sub-level of evaluation hierarchy		Pair-wise comparison matrix				Local weight	Overall weight
		Fruit firmness	Fruit water content				
Sub-level of storage quality	Fruit firmness	1.00	1.62			0.618	0.116
	Fruit water content	0.62	1.00			0.382	0.072

[a] There were totally 20 horticultural experts who participated in the comparisons for the criteria and attribute levels. In the criteria level, 100 effective questionnaires were returned with return rate of 65%, and in the attribute level, all questionnaires were returned with return rate of 72%. λ *max* is the largest eigenvalue, *CI* is the consistency index, *RI* is average random consistency index, *CR* is the final consistency ratio and the accepted upper limit is 0.1.

Table 4. TOPSIS analysis of quality indexes of tomato in 2011 and 2012 seasons.[a]

Cropping season	Treatment	Total soluble solids	Organic acid	Vitamin C	Sugar/Acid ratio	Shape index	Color index	Volume of single fruit	Weight of single fruit	Fruit firmness	Fruit water content	d_i^+	d_i^-	Q_i	Rank
2011 season	T1	0.316	0.405	0.378	0.386	0.442	0.457	0.408	0.408	0.426	0.452	0.109	0.001	0.011	5
	T2	0.413	0.411	0.417	0.422	0.445	0.461	0.465	0.465	0.428	0.450	0.078	0.043	0.356	4
	T3	0.444	0.423	0.435	0.435	0.450	0.450	0.474	0.474	0.448	0.447	0.065	0.055	0.458	3
	T4	0.449	0.541	0.483	0.487	0.456	0.437	0.453	0.453	0.457	0.445	0.037	0.082	0.685	1
	T5	0.575	0.442	0.510	0.498	0.443	0.430	0.432	0.432	0.475	0.442	0.043	0.092	0.682	2
	A^+	0.575	0.541	0.510	0.498	0.456	0.461	0.474	0.476	0.475	0.452				
	A^-	0.413	0.405	0.378	0.386	0.442	0.430	0.408	0.400	0.426	0.442				
	R	0.90*	1.00**	0.90*	0.90*	0.70	-0.80	0.20	0.20	0.90*	-0.90*				
2012 season	T1	0.340	0.509	0.381	0.418	0.443	0.458	0.386	0.369	0.424	0.453	0.093	0.039	0.296	5
	T2	0.410	0.461	0.401	0.441	0.446	0.476	0.470	0.463	0.431	0.451	0.058	0.053	0.480	4
	T3	0.461	0.429	0.459	0.449	0.449	0.445	0.503	0.505	0.448	0.447	0.040	0.077	0.657	1
	T4	0.479	0.422	0.479	0.460	0.453	0.435	0.456	0.460	0.457	0.444	0.044	0.066	0.600	2
	T5	0.524	0.407	0.503	0.467	0.445	0.420	0.412	0.428	0.474	0.441	0.059	0.072	0.550	3
	A^+	0.524	0.509	0.503	0.467	0.453	0.476	0.503	0.505	0.474	0.453				
	A^-	0.340	0.407	0.401	0.418	0.443	0.420	0.386	0.369	0.424	0.441				
	R	0.60	-0.60	0.60	0.60	0.80	-0.50	0.70	0.70	0.60	-0.60				

[a] A^+ and A^- are the positive and negative ideal solution, respectively. d_i^+ and d_i^- are the weighted Euclidean distances between each alternative and the positive or negative ideal solutions, respectively. Q_i is the comprehensive quality index. R means the Spearman correlation coefficient between comprehensive quality rank and single quality index rank, the asterisk (**) means the R was significant at the 0.01 probability level and the asterisk (*) means the R was significant at the 0.05 probability level.

Table 5. Effects of the combined use of rain shelters and deficit irrigation on total yield, evapotranspiration (ET), irrigation water use efficiency (IWUE) and water use efficiency (WUE) of tomato in 2011 and 2012 seasons.[a]

Cropping season	Treatments	Yield (t ha^{-1})	ET (mm)	IWUE (kg m^{-3})	WUE (kg m^{-3})
2011 season	T1	137.9±10.21ab	309.7±21.35a	56.7±4.17c	44.5±3.26b
	T2	156.4±9.86a	310.0±18.69a	64.9±5.36c	50.5±4.12ab
	T3	137.1±8.64ab	227.8±15.97b	81.2±6.48b	60.2±6.13a
	T4	126.4±9.37b	195.5±16.36bc	87.8±6.23ab	64.7±5.28a
	T5	118.6±6.58b	172.7±13.20c	98.8±5.82a	68.7±6.36a
2012 season	T1	149.7±12.08ab	303.8±18.95a	59.4±4.23c	49.3±4.26b
	T2	168.4±11.04a	306.8±20.18a	64.0±4.86c	54.9±3.28ab
	T3	148.4±7.91ab	225.1±13.87b	80.6±5.22b	65.9±4.39a
	T4	132.6±8.57b	192.7±18.21bc	84.0±4.68ab	68.8±5.12a
	T5	118.5±5.13c	170.7±15.28c	90.1±5.29a	69.4±5.48a

[a] *Water use efficiency= Yield/ET*. Columns with the same letter represent values that are not significantly different at the 0.05 level of probability according to the LSD test. Each value is the mean±SD (n= 3). The treatment symbols are the same as in Table 1.

condition of rain shelters, was observed, which was consistent with the former research (Topcu *et al*., 2007). Similar effects of severe water stress upon fruit weight were reported in literature (Ozbahce and Tari, 2010). The study showed that applying 50 or 60% of full irrigation amount at all growth stages decreased the average fresh fruit weight, primarily due to increased small fruit numbers. Similar findings in which decreased irrigation water affected fruit volume and the average fresh fruit weight were obtained (Cetin *et al*., 2002; Patane and Cosentino, 2010). It was because deficit water affected water accumulation in fruit and, consequently, decreased fresh fruit weight (Madrid *et al*., 2009). Water deficit promotes the ripeness of tomato and increases fruit redness. This is because water stress increased the ethylene content of tomato fruit, which in turn increased carotenoid concentration of tomato fruit, and peak lycopene content coincided with peak ethylene content (Wang *et al*., 2011). In this study, deficit irrigation increased the color index and, thus, made the pericarp color redder. However, rain shelters increases shading effect on fruit, which decreases color index.

Firmness is an important storage quality attribute of tomato. Generally, a small fruit tends to have a harder firmness due to the increased total soluble solid content and cellular density. However, other studies showed that there was no significant difference in fruit firmness between small and large fruits if fruit volume was considered (Ebel *et al*., 1993). In this study, applying 50% of full irrigation amount increased fruit firmness of tomato.

The concentrations of TSS increased with decreasing irrigation amount. Similarly, water deficits improved the quality of fruits, increasing TSS for tomatoes (Colla *et al*., 1999; Candido *et al*., 2000; Patane and Cosentino, 2010). This is because water stress increases the activities of sucrose synthase and phosphate syntheses (Qi *et al*., 2003), enlarges the gradient of sucrose concentration between leaves and fruits, which transports more assimilates into the fruits and increases the rate and amount of fructose and glucose transformation from sucrose, and thus improves fruit TSS and soluble sugar content (Kan, 2008). In general, higher contents of organic acid and soluble sugar can lead to better tomato taste quality (Bucheli *et al*., 1999). Deficit irrigation combined with rain shelters is found to be favorable for the accumulation of VC, organic acid, and soluble sugar. A similar trend for fruit acidity in response to water supply limitation is reported by Marouelli and Silva (2007). Other studies have highlighted how VC is positively affected by water limitation in processing tomato, although the extent of this effect may be cultivar-dependent. Some studies reported that the larger the fruit, the lower the VC content of tomato (Toor *et al*., 2006). The reason is that the reduced leaf area index increases light intensity and duration for fruit, and then promotes the formation of VC and lycopene (Wang *et al*., 2011; Toor *et al*., 2006).

In many cases, the fruit quality is difficult to be defined because it concerns consumer's preference. In this study, the AHP and TOPSIS methods were attempted to determine the single quality attributes importance weight and comprehensive quality index. Studies showed that T4 and T3 had the highest comprehensive quality performance in the 2011 and 2012 seasons, respectively. This is because the comprehensive quality index was determined by both the measured value and the overall weight of single quality attributes. The overall weight of a single quality attributes is determined by both the criteria weight and the number of single quality attributes included.

Previously published studies on fruit yield under water stress are similar to the data obtained in this study. According to a research carried out by Johnstone *et al*. (2005), the total yield increases in relation to the amount of water applied. Another research demonstrates that maximum tomato yields are obtainable under irrigation with water amounts based on 100% ETc (Candido *et al*., 2000). Besides, Sanders *et al*. (1989) found that fruit yield increased when the drip irrigation amount was augmented. Studies also show that rain shelters provided the best results by increasing the marketable yield of tomato by 11.87% in 2011 and 11.12% in 2012 in comparison with the control treatment. Our finding was in agreement with the results reported by Comeau *et al*. (2012).

ACKNOWLEDGEMENTS

This work was funded by key program granted by the National Nature & Science Foundation of China (No. 51009047, 51279059) and supported by the Supporting Program of the "Outstanding Young Creative Talents in Hohai University" and "Outstanding Scientific and technological Innovation Team in Jiangsu Colleges and Universities". We extend our gratitude to editor and the anonymous reviewers for substantial comments on earlier versions of this article and to Dr Kumar Prem for considerable language improvements and technical assistance and support provided.

REFERENCES

1. AOAC. 1990. *Official Methods of Analysis.* 15th Edition, Association of Official Analytical Chemists, Washington, DC.
2. Basiouny, F. M., Basiouny, K. and Maloney, M. 1994. Influence of Water Stress on Abscisic Acid and Ethylene Production in Tomato under Different PAR Levels. *J. Hortic. Sci. Biotech.*, **69:** 535–541.
3. Bucheli, P., Voirol, E., De, L., Torre, R., Lopez, J., Rytz, A., Tanksley, S. and Petiard, V. 1999. Definition of Nonvolatile Markers for Flavor of Tomato (*Lycopersicon esculentum Mill.*) as Tools in Selection and Breeding. *J. Agric. Food Chem.,* **47:** 659–664.
4. Candido, V., Miccolis, V. and Perniola, M. 2000. Effects of Irrigation Regime on Yield and Quality of Processing Tomato (*Lycopersicon esculentum Mill.*) Cultivars.

III International Symposium on Irrigation of Horticultural Crops. *Acta Horticulturae,* **537:** 779–788.
5. Cetin, ö., Uygan, D., and Boyac, H., Yildirim, O. 2002. Effects of Different Irrigation Treatments on Yield and Quality of Drip-irrigated Tomatoes under Eskisehir Conditions. *In IV Vegetable Agriculture Symposium*, 17–20, September, Bursa, Turkey. (in Turkish)
6. Colla, G., Casa, R., Cascio, B., Saccardo, F., Temperini, O. and Leoni, C. 1999. Responses of Processing Tomato to Water Regime and Fertilization in Central Italy. *Acta Horticulturae*, **487:** 531–535.
7. Comeau, C., Privé, J. P. and Moreau, G. 2012. Beneficial Impacts of the Combined Use of Rain Shelters and Reflective Groundcovers in an Organic Raspberry Cropping System. *Agr. Ecosyst. Environ.*,**155:** 117–123
8. Deng, H., Yeh, C. H. and Willis, R. J. 2000. Inter-company Comparison Using Modified TOPSIS with Objective Weights. *Comput. Oper. Res.*, **27:** 963–973.
9. Dorais, M., Papadopoulos, A. and Gosselin, A. 2001. Greenhouse Tomato Fruit Quality. *Horticultural Reviews*, **26:** 239–319.
10. Easterling, D. R., Meehl, G. A., Parmesan, C., Changnon, S. A., Karl, T. R. and Mearns, L. O. 2000. Climate Extremes: Observations, Modeling Impacts *Sci.,* **289:** 2068–2074.
11. Ebel, R. C., Proebsting, E. L. and Patterson, M. E. 1993. Regulated Deficit Irrigation May Alter Apple Maturity, Quality, and Storage Life. *HortSci.*, **28:** 141–143.
12. Ho, L. C. and White, P. J. 2005. A Cellular Hypothesis for the Induction of Blossom-end Rot in Tomato Fruit. *Ann. Bot.,* **95:** 571–581.
13. Houghton, J. T., Ding, Y., Griggs, D. J., Noguer, M., van der Linden, P. J., Dai, X., Maskell, K. and Johnson, C. A. 2001. *Climate Change 2001: The Scientific Basis*. Contribution of Working Group 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.
14. Intelmann, D., Jaros, D. and Rohm, H. 2005. Identification of Colour Optima of Commercial Tomato Catsup. *Eur. Food Res. Technol.,* **221:** 662–666.
15. Johnstone, P. R., Hartz, T. K., Lestrange, M., Nunez, J. J. and Miyao, E. M. 2005. Managing Fruit Soluble Solids with Late-season Deficit Irrigation in Drip-irrigated Processing Tomato Production. *HortSci.,* **40:** 1857–1861.
16. Kan, I. 2008. Yield Quality and Irrigation with Saline Water under Environmental Limitations: The Case of Processing Tomatoes in California. *Agr. Econ.,* **38:** 57–66.
17. Labate, J. A., Grandillo, S., Fulton, T., Muńos, S., Caicedo, A. and Peralta, I. 2007. Tomato. In: "Genome Mapping and Molecular Breeding in Plants: Vegetables", (Ed.): Kole, C.. Springer, New York, **5:** 1–125.
18. Liu, M. C. and Chen, D. K. 2002. Effect of Deficit Irrigation on Yield and Quality of Cherry Tomato. *China Vegetables,* **6:** 4–6.
19. Madrid, R., Barba, E. M., Sánchez, A. and García, A. L. 2009. Effects of Organic Fertilizers and Irrigation Level on Physical and Chemical Quality of Industrial Tomato Fruit (cv. Nautilus). *J. Sci. Food Agric.,* **89:** 2608–2615.
20. Marouelli, W. A. and Silva, W. L. C. 2007. Water Tension Thresholds for Processing Tomatoes under Drip Irrigation in Central Brazil. *Irri. Sci.,* **25:** 41–418.
21. Masaki, T. 1987. Vegetable Cultivation under the Plastic Rain Shelters. *Jpn. Agr. Res.,* **20:** 180–184.
22. Ozbahce, A. and Tari, A. F. 2010. Effects of Different Emitter Space and Water Stress on Yield and Quality of Processing Tomato under Semi-arid Climate Conditions. *Agric. Water Manage.,* **97:** 1405–1410.
23. Patane, C. and Cosentino, S. L. 2010. Effects of Soil Water Deficit on Yield and Quality of Processing Tomato under a Mediterranean Climate. *Agric. Water Manage.,* **97:** 131–138.
24. Peet, M. 1992. Fruit Cracking in tomato. *Hort. Technol.,* **2:** 216–223.
25. Pulupol, L. U., Behboudian, M. H. and Fisher, K. J. 1996. Growth, Yield, and Postharvest Attributes of Glasshouse Tomatoes Produced under Deficit Irrigation. *HortSci.,* **31:** 926–929.
26. Qi, H. Y., Li, T. L., Zhang, J., Wang, L. and Chen, Y. H. 2003. Effects on Sucrose Metabolism, Dry Matter Distribution and Fruit Quality of Tomato under Water Deficit. *Agr. Sci. China,* **2:** 1253–1258.

27. Ruiz-Altisent, M., Lleó, L. and Riquelme, F. 2006. Instrumental Quality Assessment of Peaches: Fusion of Optical and Mechanical Parameters. *J. Food Eng.,* **74:** 490–499.
28. Sanders, D. C., Howell, T. A., Hile, M. M. S., Hodges, L., Meek, D. and Phene, C. J. 1989. Yield and Quality of Processing Tomatoes in Response to Irrigation Rate and Schedule. *J. Am. Soc. Hortic. Sci.,* **114:** 904–908.
29. Sensoy, S., Ertek, A., Gedik, I. and Kucukyumuk, C. 2007. Irrigation Frequency and amount Affect Yield and Quality of Field-grown Melon (*Cucumis melo L.*). *Agric. Water Manage.,* **88:** 269–274.
30. Spiro, R. G. 1966. Analysis of Sugars Found in Glycoproteins. In: "N Methods in Enzymology", (Eds.): Eufeld, E. S. and Ginsburg, V.. Complex Carbohydrates. Academic Press, New York, **VIII:** 3–26.
31. Toor, R. K., Savage, G. P. and Heeb, A. 2006. Influence of Different Types of Fertilizers on the Major Antioxidant Components of Tomatoes. *Food Compos. Anal.,* **19:** 20–27.
32. Topcu, S., Kirda, C., Dasgan, Y., Kaman, H., Cetin, M., Yazici, A. and Bacon, M. A. 2007. Yield Response and N-fertilizer Recovery of Tomato Grown under Deficit Irrigation. *Eur. J. Agron.,* **26:** 64–70.
33. Viskelis, P., Jankauskiene, and J. and Bobinaite, R. 2008. Content of Carotenoids and Physical Properties of Tomatoes Harvested at Different Ripening Stages. *Foodbalt,* 166–170.
34. Wang, F., Kang, S. Z., Du, T. S., Li, F. S. and Qiu, R. J. 2011. Determination of Comprehensive Quality Index for Tomato and Its Response to Different Irrigation Treatments. *Agric. Water Manage.,* **98:** 1228–1238
35. Weltzin, J. F., Loik, M. E., Schwinning, S., Williams, D. G., Fay, P., Haddad, B., Harte, J., Huxman, T. E., Knapp, A. K., Lin, G., Pockman, W. T., Shaw, M. R., Small, E., Smith, M. D., Smith, S. D., Tissue, D. T. and Zak, J. C. 2003. Assessing the Response of Terrestrial Ecosystems to Potential Changes in Precipitation. *BioSci.,* **53:** 941–952.
36. Xiao, C. L., Chandler, C. K., Price, J. F., Duval, J. R., Mertely, J. C. and Legard, D. E. 2001. Comparison of Epidemics of Botrytis Fruit Rot and Powdery Mildew of Strawberry in Large Plastic Tunnel and Field Production Systems. *Plant Dis.,* **85:** 901–909.

اثر حفاظ باران و کم آبیاری روی عملکرد و کیفیت میوه گوجه فرنگی

گ. س. شاوو، س. دنگ، ن. لیو، م. ه. وانگ، و د. ل. شی

چکیده

هدف از این پژوهش تعیین اثر توام استفاده از حفاظ باران و کم آبیاری روی عملکرد و ویژگی های کیفیت محصول گوجه فرنگی بود. دو آزمایش با تیمارهای مختلف در طی فصل رشد سال های ۲۰۱۱ و ۲۰۱۲ در جنوب چین اجرا شد. در اجرای آزمایش، هنگامی که میانگین رطوبت خاک در لایه ۶۰-۰ سانتی متری به ۸۰٪ حد ظرفیت مزرعه می رسید (تیمار T1 یا شاهد در فضای باز و T2در زیر حفاظ باران) بوته ها آبیاری میشد تا رطوبت به حد ظرفیت مزعه برسد. تیمارهای دیگر ۳۰٪، ۴۰٪ و۵۰٪ کمتر از T2و به ترتیب T4،T3 وT5 بودند. نتایج نشان داد که تیمار T2 عملکرد و کارآیی مصرف آب آبیاری را معادل ۱۳٪ و۱۱/۵٪ در دوسال آزمایش افزایش داد و سفتی میوه (fruit firmness،FF) ،

[DOR: 20.1001.1.16807073.2015.17.3.4.9]

مواد جامد محلول کل، قندهای محلول، و ویتامین Cرا در مقایسه با T1بهبود بخشید. تیمارهای کم آبیاری در کشت زیر حفاظ باران عملکرد را کاهش داد ولی کارآیی مصرف آب آبیاری گوجه فرنگی را در مقایسه با T2 از مقدار ۲۵٪ به ۵۲٪ در سال ۲۰۱۱ و از ۲۶٪ به ۴۱٪ در سال بعد افزایش داد. اثر کم آبیاری روی کیفیت میوه به طور کلی برعکس اثر آن روی عملکرد بود. ازسوی دیگر، FF، مواد جامد محلول کل، قندهای محلول، و ویتامین Cو اسید های آلی و شاخص رنگ به گونه ای مثبت تحت تاثیر کم آبیاری قرار گرفت. در ارتباط با رتبه بندی با استفاده از شاخص فراگیر کیفیت (comprehensive quality index، CQI) که با فرایند تجزیه سلسله مراتبی AHP (analysis hierarchy process) و روش تغییر یافته TOPSIS(technique for order preference by similarity to an ideal solution) محاسبه شد ، برازش خوبی با رتبه بندی تک صفت کیفیت نشان داد. بیشترین CQIدرسال ۲۰۱۱ با تیمار T4 و در سال ۲۰۱۲ در تیمار T3 به دست آمد.

[DOR: 20.1001.1.16807073.2015.17.3.4.9]