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EFFECT OF SHORT-TERM DEFICIT IRRIGATION ON FRUIT QUALITY AND YIELD OF "*CRIMSON SEEDLESS*" GROWN UNDER SEMI-ARID CONDITIONS

[1*]Islam, F. Hassan, [1] Gaballah, M.S. and [2]Alaa M.Gomaa

[1] Water Relations and Field Irrigation Department. Agriculture and Biological Research Division, National Research Centre, Cairo, Egypt.

[2] Horticulture Department, Faculty of Agriculture, Suez Canal University, Ismailia, Egypt.

Abstract

A two-years (2019 and 2020) field experiment was conducted on six-year-old "Crimson Seedless" grown in a commercial farm at El-Khatatba area, El Sadat city, Egypt, to investigate the effect of applying deficit irrigation on productivity and the quality from veraison to harvest. Four irrigation levels were applied from veraison to the end of harvest as the control, based on actual crop evapotranspiration (ETo): 100% ETc (control), 80% ETc, 60% ETc and 40% ETc. As for yield, it was clear that the 100% ETc irrigation treatment recorded the greatest yield and berry parameters (berry diameter and berry firmness).In contrast, berry weight was increased by the 60% ETc irrigation treatment compared with other treatments including the control. The results indicated that decreasing the irrigation levels from 100% ETc to 40% ETc until harvest, enhanced berry color and TSS, but acidity was increased by the 100% % ETc irrigation treatment. Results suggested that pre-harvest deficit irrigation at 60 % ETc, would be the best technique to advance 'Crimson Seedless' fruit pigmentation and quality attributes with a slight effect on yield and berry parameters.

Key words: Table grapes, Crimson seedless, deficit irrigation, veraison, TSS , anthocyanins

Introduction

The Egyptian agriculture sector has been expanded in the last twenty years by reclamation of new desert lands (Hassan et al., 2019; Islam et al., 2020). New fruit trees cultivars have been cultivated, principally table grapes (*Vitis vinifera L.*), new cultivars such as Crimson Seedless that has been increasingly cultivated on a large scale in the newly reclaimed desert lands. 'Crimson Seedless' is a late-ripening, red seedless table grape variety, developed by the U.S. Dept. of Agriculture Horticultural Crops Research laboratory at Fresno, Calif. (Ramming et al., 1995). The 'Crimson Seedless' grape is considered as one of the most promising and locally distributed cultivars, due to its firm skin, late-ripening, which has led to higher pricing, good quality, and export demand. However, improving skin and flesh color along with color uniformity are vital for increased total income and farming sustainability (Acebedo-Opazo et al., 2010; Gaser et al., 2018). In semi-arid lands 'Crimson Seedless' berries often have uneven berry color, due to high or fluctuating air temperatures during berries ripening (Lo'ay, 2017). Low color appears to be correlated with the negative effect of high temperatures that prevent the formation of anthocyanin pigments that responsible of red color, in the skin of the berries (Niculcea et al, 2014). Furthermore, most of the 'Crimson Seedless' Egyptian growers provide excess irrigation to their vineyards, primarily during the ripening stage, exacerbating poor fruit color and low sugar accumulation (Bucchetti et al.,2011) .Spraying chemical growth regulators such as ethephon (2-chloroethylphosphonic acid) is commonly practiced to enhance berry color (Fernandes de Oliveira and Nieddu, 2013). However, due to high temperatures and counter-productive agriculture practices, spraying Ethephon doesn't provide sufficient berry color improvement for ''Crimson Seedless' ', especially in arid lands (Conesa et al., 2016). Deficit irrigation is a known technique to control plant growth and save water (Weiler et al., 2018). Deficit irrigation has also been shown to enhance the formation of abscisic acid (ABA) and increase fruit color (Balint and Reynolds, 2013; Faci, et al., 2014; Fuentes et al., 2014; Niculcea et al., 2014). Deficit irrigation may be used as an alternative method to spraying with plant growth regulators such as ethephon, which may have residual effects or negative influence on berry quality (Calderon-Orellana et al., 2019).

***Author for correspondence :** E-mail : islam_frahat@yahoo.com

Specifically, in wine grapes production, regulated deficit irrigation has been used to control plant vigor, as well as to improve fruit color intensity, sugar, total anthocyanins, and flavonols (Santesteban et al., 2011; Romero et al., 2013; Shellie 2014; Weiler et al ., 2018; Baeza et al., 2019). Thus, the objective of this research was to define the effects of regulated deficit irrigation levels to optimize 'Crimson Seedless' cluster color, as well as determine the best irrigation protocol during the ripening stage to provide high quality 'Crimson Seedless' table grapes under semi-arid conditions

Materials and methods

2.1. Plant material and experimental site:

This field research was conducted over two consecutive years (2019 and 2020) on six-year-old "Crimson Seedless" grapevines (*Vitis vinifera L.*) budded on 'Freedom' rootstock. Grape vines were trained on a tendone system or "Spanish Parron" system at a commercial farm located in the El-Khatatba area. El-Khatatba located at latitude 30o 52/ 66// and longitude 30o 38/ 11//, 20 to 50 meters above sea level, and within the northeast territory of Sadat City in Egypt. The climate of the study area falls within semi-arid zones, climate data means of the two growing seasons 2019 and 2020 were presented in (Table 4). 'Crimson Seedless' experimental vines were homogenous in age and growth, planted in north to south rows with 2 m spacing between vines and 3 m between rows with 700 vines per 4200 m2.

2.2. Soil type and irrigation treatments:

Experimental vineyard soil texture was a homogenous sandy loam, the physical and chemical analysis (Black et al., 1965) described in (table 1 and 2). The irrigation source was from a groundwater well (Table 3), with irrigation water total dissolves salts (TDS) 326 ppm (Richards, 1954). The irrigation method was drip irrigation, using two lines and six emitters per vine (4 L h−1). Irrigation water quantities and arranging were applied in 2019 and 2020, four irrigation treatments with ETc, were adopted from the reference evapotranspiration (ET0), using the crop coefficients proposed by (Allen et al., 1998), ETc were calculated according to equation ETc = ETo x Kc, where ETo is the reference crop evapotranspiration and Kc is the FAO table grape coefficient factor. Weather data were collected in 2019 and 2020, daily from the nearest weather station located at the 10th km, from the experimental area (Table 4). Irrigation treatments were applied carefully at the beginning of veraison stage that was measured as the moment when most of vines clusters has 20% colored and 80 %

softened berries (10 June 2019 and 14 June 2020) and completed till harvesting the crop (22 July 2019 and 27 July 2020) . The different Irrigation treatments were varied in the quantity of irrigation water applied from the beginning of veraison till the end of harvest. Irrigation treatments included, 100% from the ETc (control where the vines received 100% of their water requirements through the season), and other treatments from the beginning of veraison to the end of harvest as follows: 80% from the ETc, 60% from the ETc and 40% from the ETc. the total water requirement WR (m3/ feddan) presented in (Table 5). Soil water content in different irrigation treatments, was monitored weekly by installing soil tensiometers.

Table 1: Physical analysis of "Crimson Seedless" private farm soil.

Physical properties of the experimental soil							
Soil Depth	Coarse sand	Fine sand	Silt	Clay	Field capacity	wilting point	Bulk density
cm	%	%	%	%	%	%	(t m-3)
0-30	93.8	2.7	2.0	1.5	12	4.5	1.75

Table 2: Chemical analysis of "Crimson Seedless" private farm soil.

PH	TDS ppm	Soluble Cations, mg L^{-1}				Soluble Anions, mg L^{-1}			
	dS.m^{-1}	Ca^{++}	Mg^{++}	Na^+	K^+	CO_3^-	HCO_3^-	SO 4^{--}	Cl^-
8.5	560	4.1	2.2	7.5	1.5	-	2.1	3.7	9.5

Table 3: Chemical analysis of "Crimson Seedless" private farm irrigation water.

Irrigation water									
PH	TDS ppm	Soluble Cations, mg L^{-1}				Soluble Anions, mg L^{-1}			
	dS.m^{-1}	Ca^{++}	Mg^{++}	Na^+	K^+	CO_3^-	HCO_3^-	SO 4^{--}	Cl^-
7.2	355	1.2	2.1	1.8	2.2	2	0.3	5	1.2

Table 4: Experimental site climate data (Average of two years 2019 and 2020), and reference crop evapotranspiration (ETo) of El-Khatatba area, El Sadat city, Egypt, that calculated with CROPWAT V.8.00 computer program using FAO – Penman - Moteith equation (Smith,1992).

Meteorological factor	June	July
Min Temp °C	17.5	19.5
Max Temp °C	35.6	35.7
Humidity %	56	64
Wind km/day	190	164
Sun hours	12.60	12.30
Rad MJ/m²/day	26.3	25.7
ETo mm/day	6.62	6.30
ETc (100%)	6.23	6.12
ETc (80%)	5.10	4.89
ETc (60%)	3.73	3.67
ETc (40%)	2.49	2.44

2.3. Agricultural practices and filed management:

All the agricultural practices including pruning, spraying dormex, thinning and fertilization were performed during the experiment according to the standard agricultural practices of "Crimson Seedless" table grape, except that the two commonly conducted ethephon applications (0.5 cm L-1 at five days during the veraison stage, and 10 days after the first application were eliminated (Egyptian ministry of agriculture, recommendation book, 2019).

2.4. Yield components measurements:

Total yield (kg per vine) was determined at the time of harvest, in all the treated vines, weighting was carried out with 60 kg scale (Scaltec, Model SSH 92) with an accuracy of ±2 berry weight was measured was recorded using of a precision balance (Gram Precision Serie SV-612CM-R) with an accuracy of ±0.001 g. A digital caliper was used to measure berry diameter (mm), while berry firmness was measured by penetrometer (Effegi, Italy) having a 3 mm tip size diameter which was expressed in (Newton = N).

Table 5: The deficit irrigation levels (100, 80, 60 and 40 % from ETc) were calculated by a theoretical irrigation rate (m^3/ feddan) from June to July during 2019 and 2020.

Water requirements (W.R)	100% ETc		80% ETc		60% ETc		40% ETc	
	June	July	June	July	June	July	June	July
ETo	6.23	6.12	5.10	4.89	3.73	3.67	2.49	2.44
crop coefficient (Kc)	0.70	0.65	0.70	0.65	0.70	0.65	0.70	0.65
W.R (mm/m^2/day)	4.36	3.97	3.57	3.17	2.61	2.38	1.74	1.58
W.R (m^3/fed/day)	27.16	24.29	18.20	15.50	9.73	8.73	4.33	3.85
W.R (m^3/fed/month)	814.8	728.89	546	465.03	292.05	262.03	129.97	115.65

2.5. Quality traits:

The total soluble solids (TSS) percent of fruit juice was measured by an automated temperature to compensate refractometer (Atago ATC-1, Japan). While juice total acidity (TA) percent as a tartaric acid equivalent, was measured by diluting the juice with distilled water and titrating it with 0.1 N sodium hydroxide, reaching the endpoint of the phenolphthalein indicator (A.O.A.C., 1985). Maturity index calculated from the equation Brix/Acidity x 10. Total anthocyanins were determined using a spectrophotometer (Model UV-120-20, Japan) at wavelength 535 nm, according to Fuleki's method (Fuleki, 1986). Total phenolics content were extracted and determined according to the method described by Martínez-Esplá and associates (Martínez-Esplá et al., 2014).

2.3. Experimental design and statistical analysis:

The experimental layout was randomized complete block design; with four irrigation treatments .Each treatment had four block-replicates, each one consisted of two rows with 10 vines per row. The total numbers of vines involved in this experiment were 320 vines; the obtained data were analyzed using (Costat Statistical Software, 1990). One-way analysis of variance was carried out to compare the means of different treatments and the least significant differences at $P < 0.05$ were obtained using Duncan's multiple range test (DMRT) (Duncan, 1955).

Results

3.1. Yield, berry diameter, berry weight and berry firmness:

Data on vine yield, berry diameter, berry weight and berry firmness presented in (Table 6). In 2019, only the 40% ETc irrigation treatment had a reduced yield on a per vine basis. In contrast, all deficit irrigation water treatments in 2020 reduced yield on a per vine basis compared to the 100% ETc control treatment. A similar trend occurred with berry diameters as fruit yield with grapevines that received the 40 % ETc irrigation treatment produced smaller berries in 2019 and 2020 (15.38b and 15.53c) compared to the 100% ETc control treatment . Grapevines irrigated by 60 % ETc significantly had heavier berries (5.69 5.56 and g) both years compared to the 100% ETc control vines berries (5.36 and 5.32 g) and other water deficit treatments. While, "Crimson Seedless" grapevines irrigated by 40 % ETc had a negative influence on berry weight, the fruit weight did not differ from the 100% ETc control grapevines in 2019. Grapevines from subjected to the control irrigation treatment 100 % ETc, significantly had the firmest berries (4.55a and 4.85a) during both years. Berry firmness decrease numerically as the amount of irrigation water withheld increased for both years. However, only grapevines in 2019 that received the 40 % ETc treatment had berries that were less firms when compared to berries from grapevines that received the 60 and 80 % ETc treatments.

Table 6: Influence of deficit irrigation water treatments on "Crimson Seedless" grapevines yield, berry diameter, berry weight and berry firmness in 2019 and 2020 seasons.

	Yield (Kg vine^{-1})		Berry diameter (mm)		Berry weight (g)		Berry Firmness (N)	
Irrigation treatments	2019	2020	2019	2020	2019	2020	2019	2020
100% ETc (control)	25.0a	25.5a	16.31a	17.15a	5.36bc	5.32b	4.55a	4.85a
80% ETc	24.25a	23.0b	16.27a	16.48b	5.48b	5.41b	4.53a	4.41b
60% ETc	24.75a	23.25b	16.16a	16.26b	5.69a	5.56a	4.37b	4.35b
40% ETc	20.0b	17.5c	15.38b	15.53c	5.22c	5.15c	4.13c	4.25b

Means within each fruit yield and quality variable with the same letter are not significantly different using Duncan's test at p = 5% level.

3.2. Total acidity % and total soluble solids % :

Generally, berry total acidity and soluble solids were affected contrarily by each deficit irrigation treatments, data presented in (Table 7) indicated that, grapevines subjected to the 60% ETc irrigation treatment had fruit with the lowest titratable acidity values in 2019. At the same trend, in 2020, grapevines subjected to the 60% ETc irrigation treatment also had fruit with the lowest total acidity values along with fruit from grapevines subjected to the 80% ETc irrigation treatment.

In contrast, grapevines subjected to the 60% ETc irrigation treatment had fruits with the significantly greatest total soluble solids in 2019. Similarly, in 2020 grapevines subjected to the 60% ETc irrigation treatment also had fruits with the significantly greatest total soluble solids along with fruit from grapevines subjected to 40% or 80% ETc irrigation treatments. Regarding maturity index as shown in (Figure 1), it's clear that the decreases of irrigation water quantities comparing to the control treatment 100 % ETc positively enhanced the maturation of Crimson seedless vines.

In both seasons 2019 and 2020, the irrigation treatment 60% ETc had the superiority among all treatments followed by irrigation treatments 40% and 80% ETc compared to control treatment.

Table 7: Influence of deficit irrigation water treatments on "Crimson Seedless" fruit total acidity %(TA) and total soluble solids (TSS).

	Total Acidity (%)		Total soluble solids (°Brix)	
Irrigation treatments	2019	2020	2019	2020
100% ETc (control)	0.490a	0.475a	16.91c	17.03c
80% ETc	0.430ab	0.427b	17.57b	17.74b
60% ETc	0.347b	0.392c	18.73a	18.80a
40% ETc	0.472a	0.415b	17.81b	18.17ab

Means within each fruit yield and quality variable with the same letter are not significantly different using Duncan's test at p = 5% level.

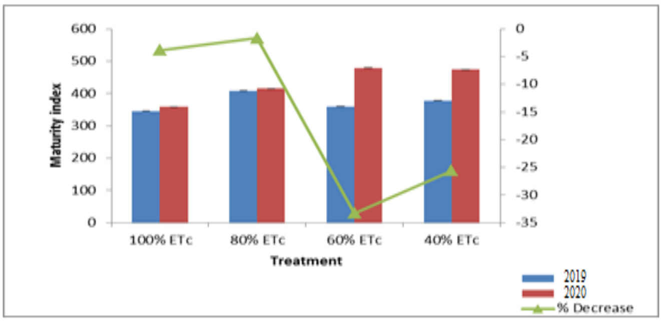

Figure 1. Influence of deficit irrigation water treatments and year on "Crimson Seedless" fruit maturity index.

3.3. Total phenolics (mg/100 g) and total anthocyanins (mg/100g):

The application of deficit irrigation between the starting of veraison until the end of harvest increased the formation of total phenolics and anthocyanins. Decreasing irrigation levels from 100 % to 60 % ETc significantly increased the formation of total phenols and anthocyanins (Table 8). However, when grapevines were subjected to the 40% ETc irrigation treatment, fruit total phenolics and total anthocyanins decreased in 2020 compared to 2019. Even though, fruit total anthocyanins remained similar to fruit from "Crimson Seedless" grapevines subjected to the 60 % ETc irrigation treatment. As shown in Figures 1 and 2, more uniform fruit color and improved red fruit color occurred when grapevines received the 60% ETc irrigation treatment compared to the 100 % ETc (control) irrigation treatment because of anthocyanin accumulation.

Table 8: Influence of deficit irrigation water treatments on "Crimson Seedless" grapevines total phenolics (mg/100 g) and the total anthocyanins (mg/100g).

	Total phenolics (mg/100 g_1 FW)		Total anthocyanins (mg/100 g_1 FW)	
Irrigation treatments	2019	2020	2019	2020
100% ETc (control)	41.0c	49.5b	17.00c	15.5c
80% ETc	41.5c	60.25a	21.75b	24.0b
60% ETc	57.0b	65.0a	25.25a	27.57a
40% ETc	64.0a	50.5b	23.ab	25.5ab

Means within each fruit yield and quality variable with the same letter are not significantly different using Duncan's test at p = 5% level.

Figure 2. The effect of 60% ETc irrigation on the quality and the coloration of "Crimson Seedless" grapevine cluster.

Figure 3. The effect of 100% ETc (control) irrigation on the quality and the coloration of "Crimson Seedless" grapevines cluster.

Discussion

The main objective of the current research paper was to enhance the color uniformity of ''Crimson Seedless'' berry, without affecting the yield or the other quality traits of fruit in the conditions of desert land. In fact, many studies were carried out to investigate the effect of long-term as well as short-term deficit irrigation, on the behavior of ''Crimson Seedless'' grapevines (Attia et al., 2010; Bucchetti et al., 2010). The results of the current study showed a slight reduction in yield, kg per vine, when the irrigation level decreased from 100 % ETc to 40 % ETc, with a superiority of irrigation level 100 % ETc, in both growing seasons. These results align with many previous studies (Attia et al., 2010; Santesteban et al., 2011). In addition, the obtained data on berry quality parameters (berry diameter and berry firmness), showed a significant decrease when irrigation levels were decreased, after veraison, from 100% ETc to 40 % ETc, with variable superiority between the irrigation level 100 % and other irrigation treatments. These results can be attributed to the negative effect of plant cell loss, as water content is transferred to the vine, and it is affected by the lower irrigation levels (Peacock et al., 1997). On the contrary, grapevines that irrigated with 60 % ETc, recorded the highest berry weight compared to control treatment and any other treatments. These results can be attributed to the increased overall solubility, including the sugars that affected berry weight compared to other berries, with lower total solubility and higher acidity (Pinillos et al., 2016; Gambetta, et al., 2020). The obtained data regarding the chemical components of berries (total acidity %, total soluble solids and maturity index), showed a significant decrease in total acidity (TA) and a remarkable increase in total soluble solids(TSS), by reducing irrigation levels from 100 % ETc to 40 % ETc, hence the maturity index increased .The decrease of irrigation water may result in increasing ABA signaling in berries, which positively contributed to the accumulation of the total soluble solids due to the loss of berry water (Deluc, et al., 2009). Furthermore, the data of the current experiment showed that reducing irrigation water from 100 % to 40 % led to a significant increase in total phenolics and enhanced berries color via increasing the accumulation of anthocyanins. The improvement of berries color as result of decreasing the irrigation water, was investigated by several previous studies (Lund , et al .,2008; Bucchetti, et al ., 2011 ; Romero, et al., 2013; Pinillos, et al ., 2016 Stevens, et al ., 2016). This can be attributed to the increased ABA signaling, which led to anthocyanin biosynthesis. According to the obtained results, it is clearly evident that reducing irrigation water, from the beginning of veraison till harvest, had a positive effect on improving the color and quality of 'Crimson Seedless' with a slight effect on yield.

Conclusions

The results of the current study indicate that the use of deficit irrigation can be applied effectively from veraison until harvest without negative effects on the yield parameters of "Crimson Seedless". In addition, reducing irrigation from 100 % ETc to 40 % enhanced the accumulation of the total soluble solids, total phenolics and total anthocyanins. Consequently, this improved red color as well as sugar content, besides shortening harvest period. These findings should be taken into consideration for managing "Crimson Seedless" irrigation during the ripening stage in private farms to solve the problem of poor color and quality in the desert lands.

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