Research Article/Araştırma Makalesi

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MEDITERRANEAN AGRICULTURAL SCIENCES
(2019) 32(3): 401-407
DOI: 10.29136/mediterranean.592723

Changes in some bioactive compounds of red cabbage (*Brassica oleracea* L.var.Rubra) under water stress

Su stresi altında yetiştirilen kırmızı lahanada (*Brassica oleracea* L.var.Rubra) bazı bioaktif bileşiklerin değişimleri

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ARTICLE INFO

Received 16 July 2019
Received in revised form 16 September 2019
Accepted 25 September 2019

***Keywords*:**

Red cabbage
Brassica
Organic acids
Water stress
Abiotic stress

ABSTRACT

A two-year study was performed on red cabbage (*Brassica oleracea* L.var.Rubra) to assess the effect of different irrigation levels on yield, sugar and organic acid contents. The study was conducted using drip irrigation system on a clay loam soil. The volume of irrigation water applied with 4-day intervals to each treatment was based on Class-A pan evaporation (Ep). In the full irrigation treatment ($I_{1.0}$), a pan evaporation using screen covered Class-A pan was measured with 4-day intervals and all amount of evaporation was applied in the normal (1.00xEp) treatment, and deficit amounts were imposed on three irrigation treatments as $I_{0.7}$ (0.7xEp), $I_{0.3}$ (0.3xEp), and $I_{0.0}$ (0.0xEp). The plant-available soil water at maturity and yield of red cabbage was significantly related to irrigation amounts. Imposition of deficit irrigation resulted in yield reduction, especially in the severe stress treatments $I_{0.3}$ and $I_{0.0}$. Therefore, yields were related linearly to irrigation. That’s why, if there is no water scarcity full water demand of red cabbage need to be compensated for the whole growing season. However, in the deficit treatment, total sugar and especially ascorbic, oxalic, tartaric and malic acid contents increased, and only lactic acid decreased, on the other hand there was no significant effect of different water levels on the content of citric acid.

MAKALE BİLGİSİ

Alınış tarihi 16 Temmuz 2019
Düzeltilme tarihi 16 Eylül 2019
Kabul tarihi 25 Eylül 2019

***Anahtar Kelimeler*:**

Kırmızı lahana
Brassica
Organik asitler
Su stresi
Abiotik stress

ÖZ

Kırmızı lahana (*Brassica oleracea* L.var.Rubra) üzerinde iki yıl süreyle yürütülen bu çalışmada farklı sulama seviyelerinin verim, şeker ve organik asit miktarları üzerine etkisi belirlenmeye çalışılmıştır. Bu çalışma killi-tın toprak bünyesi üzerinde damla sulama sistemi kullanılarak yürütülmüştür. Her bir sulama konusu 4 gün aralıklarla A-sınıfı buharlaşma kabına göre sulanmıştır. Normal sulama ($I_{1.0}$) konusunda A-sınıfı buharlaşma kabından meydana gelen buharlaşmanın tamamı (1.00xEp) uygulanmış, kısıtlı sulama konularında uygulanan sulama suyu miktarları bu uygulamanın farklı fraksiyonları $I_{0.7}$ (0.7xEp), $I_{0.3}$ (0.3xEp), $I_{0.0}$ (0.0xEp) şeklinde gerçekleştirilmiştir. Yapılan uygulamalar sonucunda, kırmızı lahananın olgunlaşma ve veriminde toprak nem düzeyinin sulama ile belli düzeyde tutulmasının önemli olduğu gözlemlenmiş ve aşırı su stresinin yaşandığı $I_{0.3}$ ve $I_{0.0}$ konularında bitkinin morfoloji ve veriminde önemli azalmaların olduğu buna bağlı olarak sulama ile verim arasında doğrusal bir ilişki olduğu belirlenmiştir. Bu nedenle suyun kıt bir kaynak olmaması durumunda kırmızı lahananın su ihtiyacının tam karşılanması gerektiği görülmektedir. Ancak, su kısıtının uygulandığı konularda toplam şeker ve asitler içerisinde; askorbik, okzalik, tartarik ve malik asit miktarlarında artış olmuş, ancak laktik asitte azalma olduğu gözlenmiştir, diğer taraftan da farklı su seviyelerinin sitrik asit içeriğinde önemli bir etki yapmadığı bu çalışma sonucunda belirlenmiştir.

1. Introduction

The nutritional aspects of foods have received more attention by many groups of scientists. Vegetables will provide food security and overcome the problems of hunger and malnutrition all over the world, since they are rich in protein, carbohydrates, vitamins and minerals. Vegetables also have some medicinal properties (Sarkar and Rakshit 2017). Red cabbage is used mostly as an ingredient in a raw vegetable salads containing a full range of vitamins and minerals with various beneficial impacts on human health (Majkowska-Gadomska and Wierzbicka 2008). Cabbage is a good source of beta-carotene, vitamin C and fibre, hence these aspects of it reduce the risk of some cancers, especially those in the colorectal group (Sharma and Rao 2013). Red cabbage prevented oxidative stress induced in livers and brains of animals exposed to paraquate (Igarashi et al. 2000) and had quite nutritional values as it was rich in minerals, vitamins, digosaccharides, and a number of bioactive substances such as anthocyanins, flavonols and glucosinolates with a positive impact on human health (Jagdish Singh et al. 2006; Podsedek 2007; Volden et al. 2008). *Brassica* vegetables are endemic to the Mediterranean region (Katay-Hazem and Hamza-AlaaEldin 2007), and red cabbage can contain 9-24 different anthocyanins (Pliszka et al. 2009). Anthocyanins are red, orange, blue or purple water soluble pigments occurring in fruit and vegetables (Wiczkowski et al. 2013). Brassica species are reported to exhibit cancer preventive activity due to glucosinolates and their derived properties (Vaughan and Geissler 1997), because of these aspects, brassica vegetables are very popular, being consumed in enormous quantities all over the world (Sousa et al. 2005), on the other hand, some research suggests that boiling these vegetables reduces their anti-carcinogenic properties (Wu et al. 2010). Therefore, consumption of it is so important for human health. These aspects of white or red cabbage indicate significant effects in prevention of diseases such as cancer. Plant metabolites are strongly affected by genetic and environmental factors as well as transpiration and storage conditions (Nilsen and Orcutt 1996). In recent years during the summer, especially in arid and semi-arid regions the required amount of water necessary for agricultural crops could not met due to erratic rainfall and water shortages caused a significant loss of crops (Kusvuran and Abak 2012). Water management is very important for preventing N leaching below the root zone and making the entire N-supply available for crop uptake (Middleton et al. 1975; Sanchez et al. 1994).

Research carried out so far on the irrigation of red cabbage focused mainly on the yield (Xu and Leskovar 2014) without considering how some chemical components change in plants under different irrigation regimes. Therefore, the present experiment was carried out to evaluate the influence of different irrigation regimes on both the yield and some chemical compounds of red cabbage.

2. Materials and Methods

2.1. *Experimental site and soil description*

Field studies were conducted at the Dardanellas Research-Extension Station of Canakkale Onsekiz Mart University, Turkey during the years 2015 and 2016 on clay-loam soil. The 90 cm soil profile hold approximately 167.7 mm of available water at field capacity. This corresponds to available soil water content of approximately 0.36. Red cabbage seedlings (*Brassica oleracea* L.var.Rubra) were transplanted on 10 July and harvested on 12 November in 2015, and on 18 July and 2 November in 2016, respectively. The climate parameters; temperature (°C) and relative humidity (%) at the site were measured by a mini-weather station with HOBO U12 sensors and data logger. Rainfall data were taken from the meteorology station 10 km from the site, as given in Table 1. Plant spacing was arranged as 0.60x0.33 m and there were four plant rows in each plot with 84 plants in total. Each row had one drip line. Buffer strips between the plots were 2 m. The distance between emitters along the drip line was 0.33 m and the discharge of an emitter was 4 l h^{-1} under the running pressure of 1-1.5 atm.

2.2. *Irrigation management*

Each plot in the experiment took the same amount of fertilizer, it included N (20%), Ammonium NH_4-N (3.4%), Nitric NH_3-N (5.3%), Ureic NH_2-N (11.3%), P_2O_5 (water soluble) (20%), K_2O (water soluble) (20%), B (0.01%), Cu (0.01%), Fe (0.05%), Mn (0.02%), Mo (0.001%), and Zn (0.02%). The total amount of fertilizer was applied three times, first at planting then at 15-day later and 20-day later after the second application.

Four irrigation management levels were included in the study. Only in the full irrigation ($I_{1.0}$= 1 x Ep) treatment, the total amount of evaporation from class-A pan within four-day intervals was applied. Deficit irrigations were imposed based on evaporation (Ep)-based water budget, 70% ($I_{0.7}$= 0.7 x Ep) which represented a range of management by irrigators, 30% ($I_{0.3}$= 0.3 x Ep), and 0% (I_0= 0 x Ep) which were considered as severe stress treatments. At the beginning of the irrigation treatments, all treatments were equally irrigated for 20 days in order to ensure equal root development. The amount of irrigation water applied with 4-day intervals was estimated by the equation given by Ertek and Kanber (2000).

$$I = A \times E_{pan} \times Kcp \times P \quad (1)$$

where I is the amount of irrigation water applied (mm), A is the plot area (m^2), E_{pan} is the cumulative evaporation at irrigation interval (mm), Kcp is the crop-pan coefficient and P is the percentage of wetted area (%).

Table 1. Meteorological data for period of experiment: temperatures (°C), relative humidity (%) and rainfall (mm).

2015			2016		
Cumulative temperature	Cumulative rainfall (mm)	Mean relative humidity (%)	Cumulative temperature	Cumulative rainfall (mm)	Mean relative humidity (%)
2797.2	67.8	57.9	2378.4	19.3	54.2

2.3. *Yield and fruit quality parameters*

All parameters were determined on 10 plant samples harvested from the center of the plot. All plant weights were measured using a digital balance (±0.01 g) and diameters were measured with a digital clipper (±0.01 mm). Leaf area was determined by a CI-202 Portable Laser area meter (CID) as cm^2. After measuring all fresh parameters, samples were all oven-dried to a constant weight at about 70°C for 48 h.

2.4. *Sugar content*

Carbohydrate (CH) content of the leaves as a reduced and total sugar concentration (glucose + sucrose + fructose) was determined by the dinitrophenol method (Ross 1959). Plants were separated into leaves and stalks, and then dried at 70°C for 48 h to reach a constant weight. Dried leaves were extracted with 15% potassium hegzasiyanoferrat, 30% $ZnSO_4$ and 6 ml dinitrophenol. Readings were taken using a T70 + UV spectrophotometer (PG Instruments, UK). The concentration of sugar (g 100 g^{-1}) was calculated according to Ross (1959).

2.5. *Organic acids*

Red cabbage pulp was extracted and the amount of them (oxalic, tartaric, malic, malonoic, lactic, citric and ascorbic acid) was determined for each sample using a HPLC system with a UV VIS^{-1} detector. For extraction of organic acids, total organic acids were determined from fresh tissue as reported by Augustin et al. (1981), with some modifications. Fresh tissue (10g) was homogenised and extracted in 50 ml of %6 HPO_3 using a blender, and then filtered through Miracloth followed by Whatman No.40 filter paper, before injection into the HPLC.

The simultaneous determination of oxalic, tartaric, malic, malonoic, lactic, citric, and ascorbic acids using liquid chromatography was carried out according to Arnetoli et al. (2005). The chromatography analysis was performed using a HPLC system (Shimadzu, Japan). The equipments of the HPLC system consisted of a LC-20AD pump, SIL-20AC Auto sampler, CBM-20A system controller, SPD-M20A Prominence DAD detector (190-800 nm), CTO-20AC column oven and LC solution (version: 1.23 sp1) software. An Inertsil ODS-III C18 column (4.6x250 ID, 5 µm particle size) was used for the chromatographic separation. The mobile phase was carried out with 125 mM KH_2PO_4 adjusted to pH 2.5 with o-phosphoric acid. The flow rate of the mobile phase and temperature of the column oven were 1.4 ml min^{-1} and 40°C, respectively. The detection wavelengths were 210 nm for oxalic, tartaric, malic, lactic, acetic and citric acids, and 254 nm for ascorbic acid (Fig. 1).

Firstly, the retention times of six organic acids were determined using single standard solution at 25 µg.ml^{-1} for each organic acid, then it was calibrated with a mix solution of all organic acids for simultaneous determination. Standard mix solution of organic acids was prepared by using oxalic acid (Sigma, 99.0%), tartaric acid (Sigma, 99.5%), malic acid (Sigma, 99.0%), lactic acid (Sigma, 98.0%), citric acid (Sigma, 99.5%), and ascorbic acid (Sigma, purity g 99.0%). Then, the equipment was calibrated with a mix solution of all organic acids at different concentrations. Unless otherwise stated, all procedures were done in triplicates.

2.6. *Statistical analysis*

The study treatments were replicated three times in a randomized complete block design. All data were subjected to analysis of variance (ANOVA) and Duncan test using SPSS for the determination of the best irrigation performance on the yield and quality parameters of red cabbage.

3. Results and Discussion

3.1. *Irrigation water and yield*

The irrigation amounts (I) and yield values for both years in the experiment are given in Table 2. Different irrigation treatments in both years had a significant effect on the yields and vegetative development of the cabbage.

Table 2. Irrigation depth and yield.

Treatments	Irrigation depth (mm)		Fresh head weight (g $plant^{-1}$)	
	2015	2016	2015	2016
$I_{1.0}$	360.9	409.2	1427.0±18.1^a	1603.0±204^a
$I_{0.7}$	252.6	277.8	1081.4±46.3^b	1219.8±75.1^b
$I_{0.3}$	108.3	186.4	620.5±14.3^c	722.9±65.0^c
$I_{0.0}$	42	51	272.6±5.90^d	167.9±25.9^d

Letters indicated significant differences between treatments at **P< 0.01.

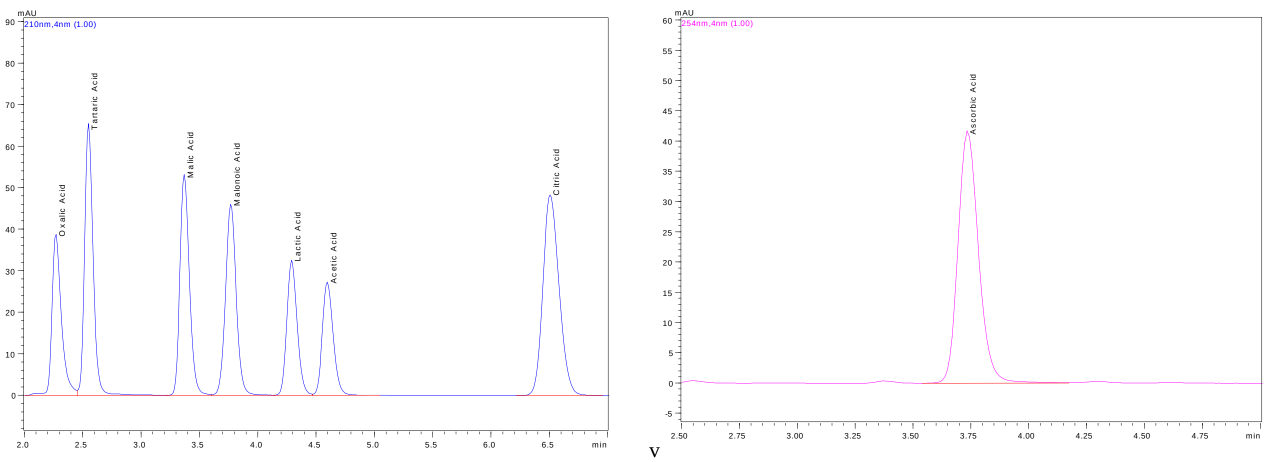

Figure 1. Chromatography spectrum of organic acids (210 nm) and ascorbic acid (254 nm).

Cabbage is classified as intermediately susceptible to water stress (Nortje and Henrico 1988). Cabbage production during fall and winter mainly depends on supplemental irrigation Xu and Leskovar (2014) and Sanchez et al. (1994) reported that cabbage yields significantly increased with water and N applications. Many researchers indicate that cabbage was sensitive to water and recommend that cabbage should be supplied with irrigation water throughout its growing season. In the present experiment, all plots received uniform irrigation during the initial 20 days after seedling, hence the amount of the irrigation water in the $I_{0.0}$ treatment in both years (42 and 51 mm) came from rainfall and the initial water applied for the first 20 days. After plant stands were established, the irrigation treatments imposed were proportional to the full water application ($I_{1.0}$). In the study, even 30% of water deficit in the $I_{0.7}$ treatment caused about 24% yield reduction in both years. In 2016, the yield of red cabbage was higher than the yield obtained in the first year, which was because of the higher rainfall in the second year, hence the amount of irrigation water increased a little bit as compared to the first year. Therefore, red cabbage is very sensitive to water deficit and the highest yield was obtained when the total water requirement of cabbage was fully met in the $I_{1.0}$ treatment. Severe stress treatments ($I_{0.3}$ and $I_{0.0}$) negatively affected morphology and yield. Wurr et al. (2002) indicated full and nearly full water applications also greener and more turgid in broccoli but the more severe stress conditions (-0.6 Mpa) deteriorated morphology and decreased yield. In the present experiment, the applied irrigation water of 409 mm resulted in the highest yield and this value can be fluctuated from 360 and 409 mm according to the climate conditions. This result well agreed with the findings in the literature. Tiwari et al. (2003) recommended that 400 mm of water was enough for the average seasonal water requirement of cabbage and they obtained the highest yield of cabbage (106 t ha^{-1}) when full water demand was compensated by a drip irrigation system. Also, 20 and 40% of water deficit decreased the yield to 105.5 t ha^{-1} and 101.45 t ha^{-1}, respectively. Acar and Paksoy (2006) obtained the highest yield of red cabbage (*Brassica oleracea* L.var.*capitata* Subvar.*F*.rubra) (28.32 t ha^{-1}) planted at a spacings of 0.6x0.5 m and irrigated by trickle irrigation method with the application of 325 mm irrigation water. Knavel and Herron (1981) reported cabbage yields were often 35 to 50 t ha^{-1}. The present yield values were very close to the results obtained by Tiwari et al. (2003) and also were greater than the other literatures. Even though the amount of irrigation water varies according to climatic conditions, it can be seen that the amount of irrigation water applied for the red cabbage varied between 300 and 400 mm.

3.2. *Quality parameters*

Different irrigation levels have a significant effect on the fruit quality parameters of cabbage. Deficit irrigation management is very important, especially in arid and semi-arid climates (Xu and Leskovar 2014). However, as shown in Table 3, a 30% decrease in the amount of irrigation water caused a decrease in yield as well as a decrease in fruit quality parameters. Severe water deficit causes photosynthesis to cease, metabolism deterioration, and ultimately to plant death.

Parameters related to plant development (fresh head, diameter, height, leaf area) were negatively affected as the amount of water decreased from 361 mm to 42 mm in 2015 and from 409.2 mm to 50.8 mm in 2016. Therefore, 30% water deficit slowed down photosynthesis and plant metabolism, resulting in reduced quality parameters of red cabbage (*Brassica oleracea* L.var.Rubra) as head diameter and height and also leaf area. Costa et al. (2007) indicated that leaf vegetables seemed to be less adapted to deficit irrigation, hence present experiment indicates that red cabbage was very sensitive crop to water deficit in terms of yield and quality parameters.

The taste of a vegetable is designated by its sugar and organic acid content (Majkowska-Gadomska and Wierzbicka 2008). In present study, significant differences were found in the content of reduced sugar and sucrose content but there were no significant differences for total sugar in both years. Primary metabolites such as; sugars, proteins, lipids and starch are of prime importance and essentially for the growth of plants. Sugar providing energy and glucose is the main source of energy because the most complex sugars and carbohydrates breakdown into glucose. The leaves, as compared to the stem and root of cabbage, contain the maximum concentration of metabolites (Santhi et al. 2011). In both years as seen in Table 4, the percent of reduced sugar were high when the full and nearly full water demand of red cabbage was compensated in the treatments of $I_{1.0}$ and $I_{0.7}$. However, this situation was the opposite for sucrose content, that is, the amount of it increased in the treatments that there were no water ($I_{0.0}$) and severe water deficit ($I_{0.3}$).

Sharma and Rao (2013) determined the sugar content as 4.00±0.65 gm gdw^{-1} in leaves and pest infected leaves of cabbage, it increased to 4.98±0.46 gm gdw^{-1}. This increment was most likely due to the stress created by pests on the cabbage. In another study, the nutritional sugar content in 13 different types of cabbage ranged from 3.83 g to 0.83 g per 100 g. Raw cabbage contains 3.90 g of sugar per 100 g (Diet and Fitness Today 2017). In the present experiment, even there were significant differences between the treatments, the highest sugar content was 5.69 g per 100 g and obtained when the full water demand of red cabbage was compensated in the first year.

3.3. *Organic acids*

Organic acids have important functions as flavor enhancers and natural antimicrobial agents. Organic acids also influence the color of vegetables since many pigments are natural pH indicators (Sinha et al. 2011).

The organic acids (ascorbic, tartaric, lactic, citric, malic and oxalic) in cabbage (*Brassica oleracea* L.cv.Rubra) are given in Tables 5 and 6. Fortier et al. (2010) observed water stress increased phenolic compounds in broccoli. Oh et al. (2009) reported cultivation under biotic and abiotic stress conditions could stimulate synthesis of bioactive compounds. Similar findings were observed in present experiment as seen in Table 5 and 6, that is, the amount of total organic acid increased when the level of water stress increased. This increment was higher in the first year, which may be attributed to the amount of rainfall during the development period. The dominant organic acids were ascorbic and oxalic. Ascorbic acid exhibited the highest content compared with the other organic acids in both years. In 2015, ascorbic acid ranged from 42.85 mg g^{-1} in the full water application to 75.81 mg g^{-1} in the severe stress treatment, which accounted for almost 73.83 % of the total organic acid content and Oxalic acid was 12.62% of it. The minor organic acids were malic, citric, lactic and tartaric and these accounted for 13.55 % of total acids. In 2016, irrigation treatments indicated the same tendency in organic acids. Fluctuations for all acid contents in red cabbage were much greater between different irrigation treatments.

Table 3. Effect of different treatments on head diameter in x and y directions, height and leaf area.

Treatments	2015				2016			
	Dia- x (cm)	Dia- y (cm)	Height (cm)	Leaf area (cm^2)	Dia- x (cm)	Dia- y (cm)	Height (cm)	Leaf area (cm^2)
$I_{1.0}$	13.5 ± 0.63^a	13.22 ± 0.58^a	15.58 ± 0.56^a	2769 ± 105^a	13.94 ± 0.43^a	13.53 ± 0.60^a	15.50 ± 0.78^a	4998 ± 194^a
$I_{0.7}$	10.9 ± 0.47^b	10.87 ± 0.51^b	12.16 ± 0.45^b	1883.4 ± 20.1^b	12.49 ± 0.12^b	12.27 ± 0.11^b	14.87 ± 0.41^b	3402 ± 203^b
$I_{0.3}$	10.0 ± 0.0.9^b	9.83 ±0.17^b	11.68 ± 0.08^b	1160 ± 164^c	10.3 ± 0.34^c	10.20 ± 0.23^c	12.36 ± 0.37^c	2677 ± 60.4^c
$I_{0.0}$	7.10 ± 0.21^c	7.19 ± 0.15^c	9.33 ± 0.33^c	716 ± 4.57^d	6.84 ± 0.23^d	6.79 ± 0.19^d	6.93 ± 0.47^d	619.2 ± 15.8^d

Dia: Diameter, numbers indicated by different letters are significantly different by the Duncan test at P<0.05.

Table 4. The amounts of reduced sugar, total sugar and sucrose (g 100 g^{-1}).

Treatments	2015			2016		
	Reduced sugar	Total sugar	Sucrose	Reduced sugar	Total sugar	Sucrose
$I_{1.0}$	4.039 ± 0.31^a	5.691 ± 0.20^{ns}	1.569 ± 0.06^c	3.669 ± 0.07^a	4.352 ± 0.09^{ns}	1.658 ± 0.08^c
$I_{0.7}$	3.811 ± 0.02^a	5.591 ± 0.02^{ns}	1.691 ± 0.03^c	3.475 ± 0.08^{ab}	4.089 ± 0.06^{ns}	1.583 ± 0.06^{bc}
$I_{0.3}$	3.001 ± 0.03^b	5.293 ± 0.02^{ns}	2.178 ± 0.03^b	3.138 ± 0.09^b	3.913 ± 0.08^{ns}	1.736 ± 0.09^b
$I_{0.0}$	2.542 ± 0.09^b	5.252 ± 0.1^{ns}	2.575 ± 0.14^a	2.705 ± 0.10^c	3.270 ± 0.28^{ns}	1.536 ± 0.15^a

ns: Not significant, numbers indicated by different letters are significantly different by the Duncan test at P<0.05.

Table 5. Fluctuations in organic acids under different irrigation levels in 2015.

Treatments		2015						Total
		Ascorbic	Tartaric	Lactic	Citric	Malic	Oxalic	
$I_{1.0}$	µg g^{-1}	42.85 ± 3.78^c	3.602 ± 0.12^c	2.870 ± 0.21^a	1.832 ± 0.21^{ns}	1.273 ± 1.00^b	9.786 ± 0.14^{ns}	62.21
	mg 100g^{-1}	4.285	0.360	0.287	0.183	0.127	0.978	6.22
$I_{0.7}$	µg g^{-1}	53.37 ± 3.87^{bc}	4.554 ± 0.13^b	3.087 ± 0.10^a	2.276 ± 0.21^{ns}	1.356 ± 1.80^{ab}	9.922 ± 0.15^{ns}	74.57
	mg 100g^{-1}	5.337	0.455	0.308	0.227	0.135	0.992	7.45
$I_{0.3}$	µg g^{-1}	64.39 ± 4.71^{ab}	4.520 ± 0.09^b	2.977 ± 0.23^a	1.953 ± 0.19^{ns}	1.582 ± 2.03^{ab}	9.639 ± 0.38^{ns}	85.06
	mg 100g^{-1}	6.439	0.452	0.297	0.195	0.158	0.963	8.56
$I_{0.0}$	µg g^{-1}	75.81 ± 0.76^a	5.360 ± 0.21^a	1.196 ± 0.06^b	2.016 ± 0.14^{ns}	1.702 ± 1.91^a	9.664 ± 0.73^{ns}	95.75
	mg 100g^{-1}	7.581	0.536	0.119	0.201	0.17	0.966	9.57

ns: Not significant, numbers indicated by different letters are significantly different by the Duncan test at P<0.05.

Table 6. Fluctuations in organic acids under different irrigation levels in 2016.

Treatments		2016						Total
		Ascorbic	Tartaric	Lactic	Citric	Malic	Oxalic	
$I_{1.0}$	µg g^{-1}	34.29 ± 2.93^c	0.602 ± 0.08^c	2.954 ± 0.47^a	2.148 ± 0.23^{ns}	0.947 ± 0.15^b	10.168 ± 0.44^b	51.13
	mg 100g^{-1}	3.429	0.06	0.295	0.214	0.094	1.016	5.113
$I_{0.7}$	µg g^{-1}	51.96 ± 1.58^b	1.220 ± 0.14^b	3.292 ± 0.36^a	1.966 ± 0.18^{ns}	1.209 ± 0.03^b	11.175 ± 0.16^b	70.82
	mg 100g^{-1}	5.196	0.122	0.329	0.196	0.12	1.117	7.082
$I_{0.3}$	µg g^{-1}	58.58 ± 0.88^{ab}	1.519 ± 0.06^b	2.402 ± 0.71^a	1.801 ± 0.15^{ns}	1.774 ± 0.05^a	11.523 ± 0.16^{ab}	77.60
	mg 100g^{-1}	5.858	0.151	0.24	0.18	0.177	1.152	7.76
$I_{0.0}$	µg g^{-1}	63.74 ± 0.82^a	2.327 ± 0.10^a	1.097 ± 0.12^b	2.408 ± 0.28^{ns}	1.969 ± 0.12^a	13.550 ± 0.60^a	85.09
	mg 100g^{-1}	6.374	0.237	0.109	0.24	0.196	1.35	8.509

ns: Not significant, numbers indicated by different letters are significantly different by the Duncan test at P<0.05.

Majkowska-Gadomska and Wierzbicka (2008) determined the content of L-ascorbic acid in varieties of Kissendrup and HacoPOL as 36.38 mg 100 g^{-1} and 31.57 mg 100 g^{-1}, respectively. In both years of the present study, the content of each individual organic acid increased with increasing water stress. Ascorbic acid known as Vitamin C is an organic acid with antioxidant properties. Vitamin C is involved in the absorption of iron and calcium. Majkowska-Gadomska and Wierzbicka (2008) found the content of copper and iron in the edible parts of red head cabbage to range from 3.57 to 6.83 mg kg^{-1} and from 52 to 50 mg kg^{-1} dry matter, respectively. Singh et al. (2007) reported that the vitamin C content of 18 different cabbage cultivars on a fresh weight basis ranged from 5.70 to 23.5 mg 100 g^{-1}. They also determined that the ascorbic acid content of white cabbage cv. Taler was higher compared to the 18 cabbage cultivars, and also higher in comparison with the other Brassica vegetables such as cauliflower, brussels sprouts and Chinese cabbage, but lower compared with broccoli. Sousa et al. (2005) identified six organic acids from tronchuda cabbage; aconitic, citric, ascorbic, malic, shikimic and fumaric, which ranged from 11 to 87 g kg^{-1}. They also indicated that the amount of organic acids could change according to the harvesting time. In the internal leaves, even though malic acid was the major compound until December, accounting for 43-87% of the total identified compounds, ascorbic acid became the main compound in January, corresponding to 57-69% of total acids. Ascorbic acid assists in the healing of wounds and burns, in preventing blood clotting and in strengthening the walls of capillaries (Carr and Frei 1999). Therefore, red cabbage can be considered as a good source in terms of all acid contents (ascorbic, tartaric, lactic, citric, malic and oxalic).

Eskin et al. (1971) reported that in fruits, the total acid content generally reaches a maximum during growth and decreases during ripening. Martinez-Villaluenga et al. (2009) indicated that the Vitamin C content in raw white cabbage was higher in cabbage cultivated in summer (373.33 mg 100 g^{-1} dry weight, equivalent to 37.30 mg 100 g^{-1} fresh weight) than that cultivated in winter (302.96 mg 100 g^{-1} dry weight, equivalent to 27.90 mg 100 g^{-1} fresh weight). Elavarasan et al. (2015) reported ascorbic acid content in cabbage changes according to the growing environment, since they obtained significantly higher content of ascorbic acid at hill grown (42.6 mg 100 g^{-1}) than at plain grown (12.92 mg 100 g^{-1}). For these reasons (climate, season etc.), many researchers have reported different amounts of organic acids for cabbage, but acid contents increase when abiotic stress increases and in the present experiment acid content was much higher than white cabbage.

4. Conclusion

In the present study, red cabbage (*Brassica oleracea* L.cv.Rubra) showed itself to be a plant sensitive to water shortage. As a mean of both years, 385 mm of irrigation water applied for the whole growing season increased the yield of cabbage. In this study, water-stress affected negatively in terms of morphology and yield but increased the amount of total acid and sugar content. Therefore, full water demand need to be compensated for preventing yield and quality. On the other hand, organic acid content was higher in cabbage cultivated under low soil water content. It is well known that organic acids support the uptake of nutrients, such as phosphorus and so on, into the plant. In this study, it was clear that organic acid content highly correlated with the amount of irrigation water and was lower when the full water requirement of red cabbage was met and this was the highlight in the present study that the plant promotes seed production as soon as possible by accelerating growth and development against water stress.

These results concerning primary organic acids and sugar content are of commercial importance and may interest in plants pharmaceuticals sector. They can also be considered as a strategy for water management in red cabbage (*Brassica oleracea* L.cv.Rubra) irrigated under semi-arid conditions.

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