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Effects of water stress on growth parameters and forage quality of globe artichoke (*Cynara cardunculus* var. *scolymus* L.)

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ABSTRACT- *Cynara cardunculus* var. *scolymus* L. is a herbaceous perennial plant that could be drought tolerant once established after the first year. To evaluate the effects of water stress on growth parameters and forage quality of this plant, a field experiment was conducted using a randomized complete block design with three replications in Isfahan, Iran during 2013-2015. Treatments were irrigation at 20 % (non-stress), 50 % (moderate stress) and 80 % (severe stress) depletion of the soil available water. Plant fresh weight (FW), plant dry weight (DW) and some forage quality characteristics such as crude protein (CP), crude fat (CF), water-soluble carbohydrates (WSC), neutral detergent fiber (NDF), acid detergent fiber (ADF), dry matter digestibility (DMD), total tannins (TT) and ash content were determined at the heading stage. Results indicated that growth and forage quality were significantly affected by water stress. The highest rates of FW, DW, NDF, ADF, CF and ash contents were recorded at non-stress conditions which were decreased over increasing stress severity by 40.67, 51.71, 6.54, 18.23, 8.83 and 21.81 %, respectively, while the highest rates of CP, DMD, WSC, and TT contents were observed at the severe water stress conditions. Generally, although water stress decreased forage yield, it had a positive role in qualitative characteristics of *Cynara* forage due to the increase in CP, DMD and WSC along with the decrease in NDF, ADF and ash content.

INTRODUCTION

Cynara cardunculus var. *scolymus* L., also known as the artichoke is a herbaceous perennial species native to the Mediterranean Basin (Gominho et al., 2009). According to the latest FAO statistics, the harvested area, yield and production of artichoke in Iran are 987 ha, 197799 kg/ha and 19527 tones, respectively (FAO, 2018). This plant has increasingly become a valuable crop due to its various uses such as food (Ierna and Mauromicale, 2010; Gominho et al., 2011) and medicine (Pandino et al., 2011; Rondanelli et al., 2011; Aksu and Altinterim, 2013). Furthermore, artichoke contains important nutritional values related to its high rates of proteins, fibers and minerals (Gebhardt 1998) and can be used as a forage crop for animal feeding such as rabbit, pig, poultry and ruminants (Bonomi, 2001; Sallam et al., 2008; Salman and Ahmed, 2014).

Water stress is considered as one of the main abiotic stresses that not only could restrict the plant growth (Grand et al., 2014) but also influence the biochemical composition of plants (Anjum et al., 2012; Erice et al., 2006). There are limited reports regarding the effects of environmental stress such as water stress on artichoke forage quality. Although artichoke is a high water requirement crop due to its high foliage yield and long production cycle (et al., 2000; Mansour et al., 2005; Shinohara 2008), it is very drought tolerant once established after the first year and can tolerate limited water condition (Fernández et al., 2006). Shinohara et al. (2011) reported that irrigation was more effective than nitrogen management to optimize artichoke yield. Kołodziej (2012) in a three-year study showed that the highest total weight of above-ground parts of the artichoke plant was obtained in treatment with additional irrigation treatment, whereas the lowest weight was obtained on plots without supplemental watering. Esteki et al. (2015) stated that this plant had the ability to keep its function to the upper limit of 50% depletion of soil available water in water stress conditions. In another study, et al. (2012) reported that applying water stress (irrigation at 60 and 80% of field capacity) on artichoke resulted in the reduction of biomass and edible flowers of this plant. In a three-year period experiment, Bahreininejad et al. (2015) indicated that the highest rate of plant height, fresh and dried herbage, days to flowering and ripening were obtained in 20% soil water depletion. Also, they reported that decreasing the effects of water stress on forage yield in the first year was higher than the second and third years. Hence, it is possible to use severe water stress for the second year for this plant. Several researchers have evaluated the effects of water stress on growth parameters and quality of forage crops. Amaducci et al. (2000) reported that dry matter digestibility of sorghum (*Sorghum bicolor* L.) increased while dry matter yield decreased when irrigation was limited. Jahanzad et al. (2013) indicated that increasing water stress from optimum irrigation to moderate and low irrigation resulted in 20 and 34% less dry matter yield of sorghum cultivar. Nohong and Nompo (2015) reported that increasing water stress duration induced reduction in plant height, number of tillers, total soluble sugar content and dry matter yield of Signal grass (*Brachiaria decumbens*) and Napier grass (*Pennisetum purpureum*). Abid et al. (2016) stated that alfalfa (*Medicago sativa* L.) had a good nutritive value under moderate water stress conditions. However, leaves, shoots and roots dry matters were reduced significantly under severe stress levels. Seguin et al. (2002) described a minor effect of water stress on CP and NDF concentration and an increased ADF concentration in *Medicago sativa*, *Trifolium ambiguum* and *T. pratense*. Küchenmeister et al. (2013) reported that the effect of drought on nutritive values of six legumes was considerably less pronounced than on yield. Erice et al. (2010) indicated that water stress caused a significant reduction of the quantity of dry matter in the above-ground and below-ground organs in alfalfa plants. Jafarian et al. (2015) reported that by increasing the severity of limited irrigation, plant growth characteristics, forage and seed yield of alfalfa followed a decreasing trend. Rostamza et al. (2011) reported that the maximum forage production of pearl millet (*Pennisetum americanum* L.) was obtained in treatments that were fully irrigated. Carmi et al. (2006) claimed that sufficient irrigation increased plant height and dry matter yield of forage sorghum and enhanced the content of neutral detergent fiber and lignin.

Artichoke, as a highly productive crop, can produce a large amount of forage per unit area. On the other hand, in many parts of the world, crop production is faced with water resources limitation. Therefore, the study of changes in forage qualitative and quantitative traits under different water scarcity levels can be necessary in field decision making for optimal production of this plant as a fodder. Therefore, the objective of this research was to evaluate the effects of three levels of irrigation regimes, representing none, medium and severe water stress levels, on growth and some qualitative characteristics of artichoke under field conditions in a semi-arid region.

MATERIALS AND METHODS

Experimental Site

This experiment was conducted in Isfahan Agricultural and Natural Resources Research and Education Center, Iran (32°36′N; 51°26′E; 1612 m above the mean sea level), during 2013 -2015. The climate of the area is semi-arid with a mean annual precipitation of 140 mm, which is received mainly during the fall and winter and an average temperature of 16 °C (Yaghmaei et al., 2009). Precipitation rate during the experiment in 2013 and 2014 is shown in Table 1. The soil of the experimental site was clay loam in texture with 7.6 pH, organic matter (0.065%), EC (2.8 dS/m), total nitrogen (0.03%), available phosphorous (14.9 ppm) and available potassium (250 ppm).

The data were subjected to a two-way ANOVA and means were separated with least significant difference (LSD) in Statistix (ver. 8, Tallahassee, FL). Figures were displayed using Excel.

Table 1. Precipitation rate (mm) during the experiment

	2013	2014
January	6.3	0.2
February	16.1	5.4
March	19.7	32.4
April	22.8	4.6
May	0.4	0
June	0	5.4
July	2.6	0
August	0	0.7
September	1.1	0.6
October	19.4	14.8
November	27.2	11.7
December	0.3	9

Design and Treatments

The experiment was designed as a randomized complete block with three replications. The treatments were irrigation at 20 % (non-stress), 50 % (moderate stress) and 80 % (severe stress) maximum allowable depletion percentage of the soil available water.

Farm Preparation

Chemical fertilizer from urea sources was applied at a rate of 100 kg N ha^{-1} before planting. Seeds were sown in late March 2013. Plot size was 5×3 m and each plot consisted of 5 rows, 5 m long with 60 cm spaced between rows and 30 cm distance between plants in the rows. The irrigation was carried out without the deficit in the first year (2013 to 2014) in order to facilitate the establishment of artichoke plants (Fig.1). The application of water stress regimes was started at the 6-leaf stage in the second year and continued until the harvesting time at the heading stage (Fig. 2). The soil moisture curve was obtained by a time-domain reflectometry (TDR) device (Model Sabta Barbara 6050X) during a period of 2 days after irrigation to 1 day prior to the next irrigation for soil water content adjustment. The experimental plots were irrigated when the respective maximum allowable depletion threshold rates were reached for each treatment and were calculated by Allen et al.'s (2000) method. Plants were harvested at the heading stage in the second year (2014).

Evaluated Traits

Plant fresh weight (FW), plant dry weight (DW) and some forage quality characteristics such as crude protein

(CP), crude fat (CF), water-soluble carbohydrates (WSC), neutral detergent fiber (NDF), acid detergent fiber (ADF), dry matter digestibility (DMD), total tannins (TT) and ash content were determined.

Plant fresh weight was determined at the harvesting time. Then, samples were dried using an oven at 65 °C for 48 h until reaching a constant weight and plant dry weights were measured by a digital scale (0.0001 g). Dried samples were grounded to 1 mm for chemical analysis. The ash content, CP, CF, NDF, ADF, DMD and WSC were estimated by near-infrared spectroscopy (NIR). Methods and details have been explained by Jafari et al. (2003). TT was measured according to the methodology described by Makkar (2003).

Fig.1. Vegetative growth stage (2013)

Fig. 2. Heading stage (2014)

Statistical Analysis

Data were analyzed using SAS software and Fisher's LSD test was used for comparison of means. Furthermore, Pearson's correlation coefficients were calculated between quality parameters.

REULTS AND DISCUSSION

Statistical analysis shows that all the traits were significantly affected by water stress levels (Table 2).

Plant Fresh Weight (FW)

Fresh weight was reduced under moderate water stress in plant and this effect was more pronounced with the severity of water stress. The highest fresh weight was seen in non-stress conditions (6866.7 kg/ha). Fresh weight decreased by 32.58 % and 40.67 % under moderate and severe water stresses, respectively (Table 3).

Plant Dry Weight (DW)

The fresh and dry weight of the plant decreased as the water stress level increased. The reduction in the fresh and dry weight of the plant could be explained by the reduction in the plant growth, photosynthesis and canopy structure as a response to water stress. Moderate water stress causes the inhibition of growth and speed of cell division in leaves. The rate of growth starts to decrease in plants as the water content falls below the point of tissue saturation with water. A longer water stress can lead to disturbances in the photosynthetic activity of the plant. The effect of drought conditions on photosynthesis rate may be due to the Rubisco activity, the reduction of stomata conductance, and reduced availability of CO_2 (Hura et al., 2007). In a similar research, Bahreininejad (2015) declared that fresh and dry weights in artichoke plant decreased in moderate and severely limited irrigation regimes that may be attributed to a reduction in plant height and leaf area under water stress conditions. In agreement with our results, Saberi et al. (2012) in sweet corn (*Zea Mays* L. convar. *saccharata*), Perrier et al. (2017) in sorghum and Saeidnia et al. (2018) in orchardgrass (*Dactylis glomerata*) also reported that water stress reduced forage yield and growth parameters of crops.

Table 2. Analysis of variance for growth parameters and forage quality indices of Artichoke

Source of variable	df	Mean squares (MS)									
		FW	DW	CP	DMD	WSC	CF	NDF	ADF	Ash	TT
Replication	2	29240263	220.23	5.33	93.63	36.67	4.11	178.20	149.40	27.21	8.003
Irrigation regimes	2	787429143**	6555715.34**	829.74 **	1378.97*	521.69*	17.63*	1311.26 *	4939.63 **	965.69 *	149.17 **
Error	4	12038534	150431.65	37.99	167.59	45.83	1.84	140.37	118.34	99.48	1.01

**significant at 1% and * significant at 5%.

Table 3. Mean comparison of forage traits and growth parameters as affected by different irrigation regimes

Irrigation treatments	FW (kg/ha)	DW (kg/ha)	CP (g/kg DM)	DMD (g/kg DM)	WSC (g/kg DM)	CF (g/kg DM)	NDF (g/kg DM)	ADF (g/kg DM)	Ash (g/kg DM)	TT (g/kg DM)
20% water depletion (I_1) (non-stress)	6866.7 ^{a}±879.25	60593 ^{a}± 7865.6	178.3 c± 5.03	589.4 b± 1.05	124.6 b± 5.52	55.5 a± 1.1	596.5 a± 9.67	437.2 a± 8.88	157.7 a± 8.14	27.5 c± 0.82
50% water depletion (I_2) (moderate water stress)	4629.7 ^{b}±879.25	37778 ^{b}± 7865.6	193.2 b± 5.03	610 ab± 1.05	140.2 a± 5.52	52.8 ab± 1.1	564 b± 9.67	410.6 b± 8.88	131.6 b± 8.14	32.8 b± 0.82

Mean values ± standard deviation (SD) followed by the same letter(s) are not statistically different by LSD ($P \leq 0.05$)

Crude Protein (CP)

Crude protein content increased by 8.36 % and 18.62 % under moderate and severe water stresses, respectively. The highest amount of protein (211.5 g/kg DM) recorded in irrigation was at severe stress (Table 3). A strong positive correlation was found between CP and DMD. Also, CP content had a positive correlation with tannin content and WSC. The correlation between ash, NDF, ADF and CF vs. CP was strongly negative (Table 4).

A variety of proteins are synthesized in response to water stress, some of which are soluble in water and contribute towards the stress tolerance phenomena (Wahid et al., 2007; Taiz and Zeiger, 2010; Farooq et al., 2009). Crude protein content has a major role in increasing the quality of fodder crops (Sun et al., 2018). The CP concentration is the result of N uptake which is greatly determined by water availability. The researchers stated that there are several cases which affect the nitrogen uptake by the plant under water stress conditions. Liu et al. (2011) and Li et al. (2013) described that plants increase root surface area and root length density under moderate water stress that facilitate nutrient uptake, thereby increasing mineral N available to plants. Researchers have reported similar results about the impact of water stress on the protein content of plants. Rostamza et al. (2011) indicated that if water stress occurred, CP% of pearl millet increased. Bibi et al. (2012) showed that increasing moisture stress increased the percentage of crude protein in sorghum-sudangrass hybrids. Fariaszewska et al. (2016) and Meisser et al. (2017) indicated that mild water stress significantly increased the content of protein in forage grasses. In contrast, some literatures have reported protein concentrations decreased under water stress conditions. For example, Khalil et al. (2015) stated that increasing water stress lowered crude protein percent in cowpea (*Vigna unguiculata*) plants. In general, depending on plant species, crude protein content in the forage crop can be negatively or positively affected by water stress.

Dry Matter Digestibility (DMD)

As the water stress severity was increased, the dry matter digestibility of forage was increased. The highest amount of DMD (632.3 g/kg DM) was observed in severe stress. The treatment of moderate stress did not show a significant difference with non-stress and severe stress (Table 3). This trait increased by 3.5 % and 7.28 % under moderate and severe water stress, respectively. The table of correlation coefficient showed a positive correlation between CP, WSC and tannin content with DMD. In contrast, ash, NDF, ADF and CF were negatively correlated with DMD. Increase in dry matter digestibility at severe stress could be attributed to its positive correlation with CP content at the same irrigation level (Table 4).

The digestibility of artichoke forage increased under water stress due to a tendency to higher CP content and WSC and lower fiber concentrations (ADF and NDF). According to Buxton (1996), a lower fiber concentration may lead to a higher herbage intake and to an increase in the digestibility of the forage. There are various results for the effect of water stress on forage quality characteristics, regarding the DMD. Carmi et al. (2006) claimed that surplus irrigation decreased dry matter digestibility of forage sorghum. Jensen et al. (2003) showed that the dry matter digestibility of orchard grass and perennial ryegrass (*Lolium perenne*) was not affected by water stress or even increased by water stress (Jensen et al., 2007). Jahanzad et al. (2013) stated that dry matter digestibility of forage sorghum cultivars increased as the amount of irrigation water decreased.

Water-Soluble Carbohydrates (WSC)

The water-soluble carbohydrates values varied from 124.6 g/kg DM at non-stress conditions to 150.8 g/kg DM at severe water stress. Results showed no statistical difference between moderate and severe water stress (Table 3). WSC content increased by 12.52 % and 21.03 % under moderate and severe water stresses, respectively. Ash, NDF, ADF contents and CF had a negative correlation with WSC content. For WSC vs. tannin content, correlation was positive and significant (Table 4). This trait has a positive influence on fodder intake (Küchenmeister et al., 2013). WSC values followed an increasing trend as the severity of water stress increased. Artichoke responded to water stress, as in some other crops, with an increase in WSC content. The osmotic adjustment is a physiological mechanism in response to drought stress (DaCosta and Huang, 2006). According to Nakayama et al. (2007), an increase in the WSC concentration in plants will change the osmotic potential, which maintains the uptake of soil water under water stress conditions. Many researchers point to the role of soluble sugars in the protection

Table 4. Pearson correlation between some qualitative parameters of artichoke

Traits	CP	DMD	WSC	NDF	ADF	Ash	CF	TT
CP	1							
DMD	0.85**	1						
WSC	0.83**	0.87**	1					
NDF	-0.73*	-0.69*	-0.74*	1				
ADF	-0.88**	-0.80**	-0.84**	0.80**	1			
Ash	-0.92**	-0.75*	-0.77*	0.81**	0.74*	1		
CF	-0.82**	-0.84**	-0.68*	0.54	0.64	0.72*	1	
TT	0.91**	0.90**	0.84**	-0.66	-0.87**	-0.76*	-0.92**	1

**. Correlation is significant at the 0.01 level. *. Correlation is significant at the 0.05 level.

against water stress. Accumulation of soluble carbohydrates increased resistance to the drought in two soybean (*Glycine max* L. Merrill) cultivars. Weinberg et al. (2007) showed that more water-soluble carbohydrates were produced in safflower (*Carthamus tinctorius*) under water stress. They also reported a negative correlation between complementary irrigation and WSC. Mohammadkhani and Heidari (2008) reported that a higher amount of soluble sugars was obtained from two maize cultivars under water stress conditions. Nazarli and Faraji (2011) described that water stress resulted in higher sugar components in wheat (*Triticum aestivum* L.) cultivars. Küchenmeister et al. (2013) indicated that the influence of water stress on WSC concentrations of perennial forage legumes was generally small, but there was a trend to higher concentrations under severe water stress. Homayouni and Khazarian (2014) reported that reduced irrigation caused an increase in sugar components in the maize plant. Meisser et al. (2017) noted that WSC in forage grasses increased under mild water stress

Crude Fat (CF)

Crude fat content was reduced by increasing water stress severity. The highest CF (55.5 g/kg DM) was observed in non-stress conditions. This trait decreased by 4.86 % and 8.83 %, respectively under moderate and severe water stress. There were no significant differences between the moderate water stress with non-stress and severe water stress (Table 3). There was no significant correlation between NDF, ADF and CF, but a positive correlation was observed between CF content and total ash. Correlations were strongly negative for CF vs. CP, DMD, WSC and TT (Table 4).

Researchers showed that water stress can change the crude fat content of different species plants. Onwugbuta-Enyi (2004) reported that crude fat contents in cowpea seedlings were found to be very low in the water-stressed plants. Bibi et al. (2012) showed that the crude fat of sorghum-sudangrass hybrids decreased as a result of water stress as compared to normal irrigation. Osuagwu and Edeoga (2013) showed that water stress caused a significant reduction in the crude fat content of the leaves of African basil (*Ocimum gratissimum* L.) and Bush buck (*Gongronema latifolium* Benth.). They also explained that this might be caused by the breakdown of fats to form highly osmotic materials to aid the plants to withstand the water stress.

Neutral Detergent Fiber (NDF)

As the water stress increased, the NDF content decreased (Table 3). The minimum value of NDF (557.5 g/kg DM) was recorded at severe stress. NDF content decreased by 5.45 % and 6.54 % under moderate and severe water stresses, respectively. There were no significant differences between severe and moderate water stress conditions. Ash content and ADF had a positive correlation with NDF. Other traits (CP, DMD and WSC) were negatively correlated with NDF content (Table 4).

NDF is an indicator of cell wall components (including cellulose, hemicellulose and lignin) and is inversely correlated with the quality of forage. Fiber concentration is usually influenced by many factors such as the stage of plant development, leaf-stem ratio, environmental conditions (drought, temperature, photoperiod etc.) or availability of nutrients (Peterson et al., 1992; Buxton, 1996; Fulkerson et al., 2007). Peterson et al. (1992) and Buxton (1996) reported that a delayed maturity in plants under drought condition is associated with lower NDF and ADF concentrations. There are a number of reports regarding the impact of water stress on the neutral detergent fiber of the plant. Küchenmeister et al. (2013) studied six perennial forage legumes in monoculture and in mixture with perennial ryegrass under water stress conditions. They found decreases in NDF under strong stress. Abid et al. (2016) investigated the effect of different irrigation levels on nutritive quality for three populations of alfalfa. They reported that drought has a significant effect on fibers contents. The NDF content decreased from 41.33% under control conditions to 35.73% under 25% of field capacity.

Acid Detergent Fiber (ADF)

The ADF was reduced by increasing water stress severity. According to Table 3, the highest ADF value (437.2 g/kg DM) was obtained under non-stress conditions. This trait was decreased by 6.08 % and 18.23 % under moderate and severe water stress, respectively. There was a positive correlation between NDF and ash with ADF. In contrast, ADF was negatively correlated with TT, CP, DMD and WSC (Table 4). ADF content provides an estimate of the cellulose and lignin which relates negatively to forage digestibility. A lower concentration of ADF may lead to an increase in the digestibility of artichoke forage and to a higher herbage intake. Moore et al. (2008) stated that longer exposure to water stress challenges plants to alter their cell walls to sustain growth under conditions with reduced water potential. These results were in agreement with those of other researchers indicating that ADF content of the plant was decreased as the result of water stress. Küchenmeister et al. (2013) found a decrease in the ADF percentage of perennial forage legumes under strong stress. Abid et al. (2016) indicated that ADF values of alfalfa reduced under severe water stress.

Ash

The ash content was decreased by an increase in water stress severity. Ash varied from 123.3 g/kg DM in severe water stress to 157.7 g/kg DM in non-stress conditions. The treatments of moderate and severe water stress were grouped in the same statistical category (Table 3). Ash content decreased by 16.55 % and 21.81 % under moderate and severe water stresses, respectively. Total ash had a positive and significant relation with CF, NDF and ADF, while the correlation between ash content and the other quality traits (CP, DMD, WSC and TT) was negative and significant (Table 4).

In a water stress condition, the nutrients are less accessible by the plant's root (Steudle, 2000). Generally, ash content can be an indicator of total minerals in plant. The decrease in ash content under water stress is reported in the literature. Haji Hassani Asl et al. (2011) reported that ash content in three forage crops including corn, sorghum and millet decreased significantly by water stress. Ash content of sorghum-sudangrass hybrids was reduced as a result of water stress compared to control treatment (Bibi et al., 2012). Water stress significantly decreased ash percentage in two hybrids of maize (Shoaei and Rafiei, 2014). Khalil et al. (2015) found that a significant reduction occurred in ash content of cowpea plants under water stress environment and stated that this may be due to the result of reduced soil nutrient availability and uptake with decreasing water soil content, or as a consequence of limited energy source (carbohydrates) supplied by leaves being affected by water stress.

Total Tannin (TT)

Tannin was increased as the severity of water stress increased. The maximum value of tannin content (41.5 g/kg DM) registered in severe water stress is shown in Table 3. This trait increased by 19.27 % and 50.91 % under moderate and severe water stress, respectively. According to the results of correlation (Table 4), for tannin content vs. CP, DMD and WSC, a significant positive correlation was observed while the correlation between tannin content and the other quality traits (ash, CF and ADF) was significantly negative. Tannins are phenolic compounds from the secondary metabolism of the plants that possess anti-nutritional and anti-feed properties (Mueller-Harvey, 2006; Souza et al., 2007) and can play a great influence on the forage nutritional value. Hagerman and Butler (1981) reported that the usefulness or harmfulness of tannins depends on the amount consumed, structural components, molecular weight, and animal physiology. Tannins have the ability to form digestion-resistant compounds with proteins as well as to direct inhibitory effects on microbial activity that led to a decrease in tissue digestibility and decomposition rate (Mueller-Harvey, 2006). When supplied at high concentrations (6-12% DM), it may cause a decrease in the voluntary intake and in the efficiency of the digestion process and animal productivity (Frutos et al., 2002). Some literatures have reported decrease or increase tannins concentrations under water stress. For example, drought increased the polyphenol levels in perennial ryegrass and alfalfa (Farfan-Vignolo et al., 2012). Anuraga et al. (1993) noted that condensed tannin concentrations were increased as a result of drought and/or high-temperature stress in Bird's-foot trefoil (*Lotus corniculatus*) and formerly Lotus uliginosus (*Lotus pedunculatus*). In contrast, a reduction in condensed tannin contents was also observed under water stress in *L. corniculatus* leaves (Carter et al., 1999). Tannins were markedly decreased in perennial ryegrass and Kentucky bluegrass (*Poa pratensis*) as a result of the drought and warming (AbdElgawad et al., 2014).

This paper presented an experiment which showed that the growth parameters and quality traits of artichoke were significantly affected by water stress. As the water stress severity increased, the CP, DMD, WSC and TT content followed an increasing trend while NDF, ADF, CF, ash contents as well as fresh and dry weight of the plant followed a decreasing trend. Total tannin content was less than the harmful rate in all treatments. Severe water stress led to the increase in CP, DMD and WSC concentrations and the decrease in NDF and ADF concentrations, which enhanced the digestibility of the forage. Overall, although water stress decreased forage yield, it had a positive role in qualitative characteristics of *Cynara* forage due to the increase in CP, DMD and WSC contents along with the decrease in NDF, ADF and ash contents.

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تحقیقات کشاورزی ایران (۱۳۹۸) ۳۸(۲)۱۰۱-۱۱۰

تأثیر تنش رطوبتی بر پارامترهای رشد و کیفیت علوفه کنگرفرنگی (*Cynara cardunculus* var. *scolymus* L.)

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واژه‌های کلیدی:
کنگر فرنگی
پروتئین خام
قابلیت هضم ماده خشک
رژیم‌های آبیاری
تانن کل

چکیده- کنگرفرنگی گیاهی علفی و چند ساله است که می‌تواند بعد از استقرار در سال اول رویش، به خشکی متحمل باشد. برای ارزیابی تأثیر تنش کمبود آب بر رشد و کیفیت علوفه این گیاه، آزمایشی با استفاده از طرح بلوک‌های کامل تصادفی با سه تکرار در اصفهان طی سال‌های ۹۳-۱۳۹۱ انجام شد. تیمارهای آبیاری شامل ۲۰، ۵۰ و ۸۰ درصد تخلیه رطوبت قابل استفاده در خاک (به ترتیب بدون تنش، تنش متوسط و شدید) بودند. وزن‌تر و خشک گیاه و برخی از خصوصیات کیفی علوفه شامل پروتئین و چربی خام، کربوهیدرات‌های محلول در آب، الیاف نامحلول در شوینده خنثی و اسیدی، قابلیت هضم ماده خشک، تانن و میزان خاکستر تعیین شد. نتایج نشان داد که پارامترهای رشدی و کیفیت علوفه تحت تأثیر تنش کمبود آب قرار گرفت. حداکثر وزن تر و خشک گیاه، الیاف نامحلول در شوینده خنثی و اسیدی، چربی خام و خاکستر در تیمار بدون تنش ثبت شدند که با افزایش شدت تنش به‌ترتیب ۴۰/۶۷، ۵۱/۷۱، ۶/۵۴، ۱۸/۲۳، ۸/۸۳ و ۲۱/۸۱ درصد کاهش یافتند، در حالی‌که بیشترین میزان پروتئین خام، قابلیت هضم ماده خشک، کربوهیدرات‌های محلول در آب و محتوای تانن در تنش شدید مشاهده شدند. به طور کلی، اگرچه تنش رطوبتی باعث کاهش عملکرد علوفه شد لیکن از طریق افزایش میزان پروتئین خام، قابلیت هضم ماده خشک و کربوهیدرات‌های محلول در آب و کاهش میزان الیاف نامحلول در شوینده خنثی و اسیدی و خاکستر نقش مثبتی بر خصوصیات کیفی علوفه کنگرفرنگی داشت.