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Determination of Forage Quality Properties of Plant Parts in Different Amaranth Varieties Cultivated Under Irrigated and Rainfed Conditions

Sulu ve Kuru Koşullarda Yetiştirilen Farklı Amarant Çeşitlerinde Bitki Kısımlarının Yem Kalite Özelliklerinin Belirlenmesi

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ABSTRACT

There is not enough information about how the feed quality changes according to plant parts and growing conditions in Amaranth species used as an alternative feed source. For this purpose, a three-replication study was conducted in randomized blocks according to the split plot design to determine the feed value of leaves, clusters and stems of Helios, Sterk and Ultra cultivars grown under irrigated and dry conditions in 2017-2018. The results of the study showed that the highest crude protein (HP), dry matter digestibility (KMS), metabolic energy (ME), relative feed value (NYD) and lowest natural solvent insoluble fiber (NDF) and acid solvent insoluble fiber (ADF) contents. showed that it was obtained from Ultra grown in irrigated conditions. On the other hand, the highest cluster and stem HP ratio was determined in Helios grown under irrigated conditions, while the highest cluster and stem HP were determined in KMS, ME and NYD cultivars grown in irrigated Ultra and Helios grown in dry conditions. In addition, HP, KMS, ME and NYD of leaves were higher than clusters and stems, whereas NDF and ADF contents were lower, respectively. As a result, it was revealed that the leaves and inflorescences of the examined cultivars produced a higher quality forage material under irrigated conditions, while the stems produced a lower quality forage material in dry (except HP).

Keywords: Amaranth species, feed quality, growing conditions, morphological parts

ÖZ

Alternatif yem kaynağı olarak kullanılan Amarant türlerinde yem kalitesinin bitki kısımları ve yetişme koşullarına göre nasıl bir değişim gösterdiği konusunda yeterli bilgi bulunmamaktadır. Bu amaçla, 2017-2018 yıllarında sulu ve kuru koşullar altında yetiştirilen Helios, Sterk ve Ultra çeşitlerinin yaprak, salkım ve sapların yem değerini belirlemek için tesadüf bloklarında bölünmüş parseller deneme desenine göre üç tekerrürlü bir çalışma yürütülmüştür. Araştırma sonuçları en yüksek ham protein (HP), kuru madde sindirilebilirliği (KMS), metabolik enerji (ME), nispi yem değeri (NYD) ile en düşük doğal çözücülerde çözünemeyen lif (NDF) ve asit çözücülerde çözünemeyen lif (ADF) içeriklerinin sulu koşullarda yetiştirilen Ultra'dan elde edildiğini gösterdi. Diğer taraftan en yüksek salkım ve sap HP oranı sulu koşullarda yetiştirilen Helios'da belirlenirken, en yüksek salkım ve sap KMS, ME ve NYD ise suluda yetiştirilen Ultra ile kuruda yetiştirilen Helios çeşitlerinde tespit edildi. Ayrıca yaprakların HP, KMS, ME ve NYD sırasıyla salkım ve saplardan daha yüksek, oysa NDF ve ADF içerikleri ise daha düşük bulundu. Sonuç olarak incelenen çeşitlerin yaprak ve salkımları sulu koşullar altında daha yüksek kalitede, sapları ise kuruda (HP hariç) daha düşük kalitede bir yem materyali ürettiği ortaya konulmuştur. sapları ise kuruda (HP hariç) daha düşük kalitede bir yem materyali ürettiği ortaya konulmuştur.

Anahtar Kelimeler: Amarant türleri, *yem kalitesi, yetişme koşulları, morfolojik kısımlar*

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Introduction

Knowledge of feed quality is as important as the amount of feed given to animals for achieving high animal product performance. Because quality of the fodder crop is defined as the ratio of transformation of the consumed feed to the animal product, which varies as to nutritional value and digestibility of the feed (Collins & Fritz, 2003). Nutritional value of the feed and its digestibility are significantly affected by environmental factors (climate, soil, etc.), plant characteristics (species, variety, maturity, etc.), and cultural practices (irrigation, fertilizing, etc.) (Keskin et al., 2021; Önal Aşcı & Acar, 2018; Tan & Temel, 2019; Temel & Tan, 2020; Temel & Yolcu, 2020). In general, anatomical, morphological, and chemical structures of plants may differ among species, varieties, and plant parts (Fales & Fritz, 2007). In studies conducted on different forage plant species and varieties, it was revealed that leaves contain two to three times more crude protein and lower acid detergent fiber (ADF) and neutral detergent fiber (NDF) ratios than the stems (Fales & Fritz, 2007; Hatfield et al., 2007). For example, in the quinoa plant that is considered as a feed source, it was reported that the panicles and, particularly, the leaves had at least three times higher crude protein (CP), dry matter digestible (DMD), metabolic energy (ME), and relative feed value (RFV) than that of the stems, while they had at least three times lower NDF and ADF contents (Temel & Keskin, 2020). In addition, scarcity and abundance of water in cultural practices may positively or negatively affect the quality of the feed by stressing out the plants (Buxton & Fales, 1994).

Amaranth (*Amaranthus* spp.), which can adapt well to different environmental conditions, poor soil, and scarcity of water, is a pseudo cereal with high nutritional value (Pospišil et al., 2009). Most of the species in this genus show weed characteristics (Khan et al., 2019); however, they are widely used in human nutrition because of their highly nutritional grains and leaves (Adhikary et al., 2020; Alegbejo, 2013; Amicarelli & Camaggio, 2012). The interest in amaranths has also been significantly rising in recent years due to its high yield of high nutritional forage (Peiretti, 2018), and all vegetative parts of the plant (stem, leaves, and panicles) are preferred as alternative feed sources in animal nutrition in the forms of fresh or dried forage, silage, and grain feed (Leukebandara et al., 2019; Sarmadi et al., 2016; Svirskis, 2003; Temel et al., 2020). On the other hand, although nutritional value and digestibility of amaranths, which are harvested as a whole plant, vary according to species, varieties, sowing frequency, fertilizer applications, and development stages (Keskin et al., 2020; Leukebandara et al., 2015; Rahnama & Safaeie, 2017), it was demonstrated that the feed quality is higher than the widely grown grain and many fodder species and is sufficient for animal feeding (Pond & Lehmann, 1989; Pospišil et al., 2009; Sleugh et al., 2001). However, it is seen that the number of research for determining the feed quality of the plant parts (leaf, panicle, and stem) is less and the obtained results are generally from studies conducted by considering only a single growing condition (irrigated) (García-Pereyra, 2009; Svirskis, 2003). Therefore, there are no studies that are conducted to analyze the feed quality characteristics of the varieties belonging to *Amaranthus caudatus*, *Amaranthus hiybridus*, and *Amaranthus paniculatus* × *Amaranthus nutans* species grown in irrigated and rainfed farming systems by considering different plant parts.

The present research is planned with the aim of determining the changes in feed quality of varieties belonging to *Amaranthus spp.* according to different growing conditions and plant parts. In this way, besides the contribution of plant parts to the feed quality, appropriate growing conditions and varieties with the highest feed quality were determined.

Methods

The research was carried out in the Agricultural Research and Application Center trial area of a university, located at an altitude of 876 m, between 2017 and 2018. The region where the study was conducted has Turkey's most arid climate with low annual rainfall and high evaporation ratio. Looking at some climatic values of the research area, total precipitation, average temperature, and relative humidity according to long-year averages were measured as 267.6 mm, 12.4°C, and 54.5%, respectively. In 2017 and 2018 during which the experiment was carried out, average annual temperatures were recorded as 12.4°C and 15.1°C, average relative humidity at 58.4% and 60.0%, and annual precipitation amounts as 220.8 mm and 280.0 mm, respectively. According to this data, it can be seen that 2017 was drier (220.8 mm), while there was more rainfall (280.0 mm) in 2018, according to long-year averages (267.6 mm). Moreover, average temperature (15.1°C) and rainfall (280.0 mm) in 2018 when the trial conducted was measured to be higher than those (12.4°C and 220.8 mm) in 2017 (MGM, 2019).

More than one-third of the Iğdır plain soils have lost their productivity due to salinity and remained out of production (Temel & Şimşek, 2011). Similar soil structure is also found in the field of Agricultural Research and Application Center. However, while selecting the trial area, such areas with extremely saline soil characteristics were avoided. In both research years, sufficient amount of soil samples (4.0 kg) was taken by a hole digger from different points (0–30 cm deep) to represent the research area before sowing, and the analyses were carried out at the Research Laboratory Practice and Research Center of a university. The findings of the analysis revealed that the soils had a clay-loam texture, being a medium alkaline character (pH: 8.45), with low salt (1.43 dS/m), organic matter (1.06%), available potassium (1.66 ppm) content, very low phosphorus (2.29 ppm), and medium lime (10.7%), medium calcium (15 ppm), and magnesium (6.2 ppm) content (Ulgen & Yurtsever, 1995). In addition, the field capacity of the trial site soils was measured as 26.0% and the wilting point as 9.1%. Helios, Sterk, and Ultra varieties and leaves, stems, and panicles of these varieties were used as plant material while irrigating and rainfed farming conditions were used as trial materials in the research.

Helios variety with light green leaves is a type of grain with high-fat content that belongs to *A. caudatus* (Yaroshko & Kuchuk, 2018). Sterk was developed as a variety resistant to high humidity and temperature stress as a result of mutation breeding in Russia. It is a variety developed in 1992 by applying chemical mutagens to hybrid seeds of *A. paniculatus* × *A. nutans* (Jafari et al., 2018). Ultra, on the other hand, is a variety belonging to *A. hybridus* species which is developed for short vegetation periods. Its leaves are light green and the seeds are white. It was registered in Ukraine in 1998 (Goptsiy et al., 2008).

The experiment was established on randomized complete block design with three replicates under irrigated and rainfed conditions. Area of each plot was set to 9.8 m^2 (3.5 m × 2.8 m) by leaving 1.2 m spaces between blocks. The sowings were made by hand into furrows of 1.5 cm sowing depth prepared by a marker, with 70 cm row spacing and 15 cm intra-row spacing (Svirskis, 2003). In the first year, sowings were carried out on April 14, 2017, and in the second year, sowings were carried out on March 25, 2018. Soil and climate conditions unsuitable for sowing were the reason for the difference in sowing dates. Fertilization was carried out during the seedbed preparations by applying 50 kg pure N (21% ammonium sulfate) and 100 kg pure P_2O_5 (46% triple superphosphate) per ha. Moreover, an additional 50 kg of pure N (21% ammonium sulfate) per ha was also applied when plants reached 30 cm of height (Myers, 1998). In addition to the existing rainfall in dry conditions, the development of the plant was achieved without any irrigation. In irrigation conditions, after determining the field capacity (26%) and the wilting point (9.1%) of the soil, irrigation was started when 50.0% (8.45%) of the available water holding capacity (16.9%) was consumed. The moisture content of the existing soil was followed by the soil moisture meter. Irrigation was started with the sprinkler irrigation system when the moisture content in the soil was seen as 17.55% in the soil moisture meter. Irrigation was terminated when the moisture content of the soil at a depth of 30 cm reached the field capacity (26.0%). During the growing period under irrigated conditions, the plants were irrigated four times in 2017 and five times in 2018. Moreover, weeds detected in the trial area were controlled by hand-picking and by hoeing. Harvests in all varieties were done by hand at the beginning of flowering at a 7.5 cm soil level (Fazaeli et al., 2011; Leukebandara et al., 2015). However, harvests were carried out on different dates as to variety, year, and growing conditions. In both years, Ultra was the first variety to reach harvest maturity under rainfed conditions (on July 1, 2017, in the first year and on June 20, 2018, in the second year) and was followed by Sterk and Helios, respectively, within 10-day intervals. In addition, varieties grown under irrigated conditions were harvested 1 week later, on average, than varieties grown under rainfed conditions in both years.

During the harvest period, 10 randomly selected plants in the harvest area were cut and separated from stems, leaves, and panicles. The separated parts were first dried in open air for 3–4 days and then in a drying oven set at 70°C until their weights were stabilized. After that, dried samples were prepared for chemical analyses by grinding in a mill with a sieve diameter set at 1 mm. Crude protein content of plant parts was found by multiplying the N% ratio determined by Micro Kjeldahl method by the coefficient of 6.25 (AOAC, 1997). Acid detergent fiber and neutral detergent fiber contents were determined by the method developed by Van Soest et al. (1991). Dry matter digestibility (DMD = (88.9-(0.779×ADF %)) and relative feed value (RFV=(DMD×DMC)/1.29) were determined by the method suggested by Boman (2003), while metabolic energy (ME Mcal/kg = (0.821×DE Mcal/kg)) content was determined by the equation developed by Khalil et al. (1986). In addition, dry matter consumption (DMC = (120/NDF%)) and digestible energy (DE Mcal/kg = (0.27+0.0428×(DMD%))) values used in the formulas were calculated by the equation suggested by Fonnesbeck et al. (1984).

Statistical Analysis

The results were subjected to variance analyses according to split plots in randomized block design by using JMP 5.0.1 statistical software package, and the grouping of the means which were found to be significant was conducted by the LSD (Least Significant Difference) test.

Results

The results obtained in the study conducted to determine the nutritional contents of plant parts of different *Amaranth* spp. varieties cultivated under irrigated and rainfed conditions for 2 years were subjected to statistical analysis, and the significance levels and LSD values of the parameters examined are presented in Table 1.

Table 1.
LSD Values and Significance Levels of the Examined Parameters

Variation Sources	Leaf CP	Panicle CP	Stem CP	Leaf NDF	Panicle NDF	Stem NDF	Leaf ADF	Panicle ADF	Stem ADF
Y	.65**	n.s.	.94**	1.73**	.95**	.70**	n.s.	.61**	1.60**
GC	.65**	.64**	.94**	n.s.	n.s.	.70**	.44**	.61*	1.60**
Y × GC	.91*	n.s.	n.s.	2.44**	1.35*	1.00**	n.s.	n.s.	n.s.
V	.62**	.65**	n.s.	2.14*	1.09**	1.69**	.38**	.60**	1.18**
Y × V	.87**	.92**	1.15**	3.02**	1.55**	2.39*	.54**	.84**	1.67**
GC × V	.87**	.92**	n.s.	3.02**	1.55*	2.39**	.54**	.84**	n.s.
Y × GC × V	1.23*	1.31**	1.62*	n.s.	n.s.	n.s.	.76**	n.s.	2.36**
Variation Sources	**Leaf DMD**	**Panicle DMD**	**Stem DMD**	**Leaf ME**	**Panicle ME**	**Stem ME**	**Leaf RFV**	**Panicle RFV**	**Stem RFV**
Y	n.s.	.47**	1.25**	n.s.	.02**	.04**	22.5**	5.0**	4.6**
GC	.35**	.47*	1.25**	.01**	.02*	.04**	n.s.	n.s.	n.s.
Y × GC	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	31.8*	n.s.	6.5**
V	.29**	.46**	.92**	.01**	.02**	.03**	20.7**	5.7**	6.7**
Y × V	.41**	.65**	1.30**	.01**	.03**	.04**	29.3**	8.1**	9.5**
GC × V	.41**	.65**	n.s.	.01**	.03**	n.s.	29.3**	8.1**	9.5*
Y × GC × V	.59**	n.s.	1.84**	.02**	n.s.	.06**	41.5*	n.s.	n.s.

Note: *$p < .05$, **$p < .01$.

ns = non-significant; Y = Year; GC = growing condition; V = variety; CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; DMD = dry matter digestibility; ME = metabolic energy; RFV = relative feed value.

Mean leaf, panicle, and stem CP contents of plant parts of *Amaranth* spp. varieties grown under irrigated and rainfed conditions are given in Table 2. When Table 2 was examined, it was seen that the leaf and stem CP contents of the plants were higher in 2018 compared to 2017, and the leaf, panicle, and stem CP contents of the plants were higher under irrigated conditions. This may have resulted from the fact that plants exposed to water stress (in 2017 and in the dry) reached form maturity at an earlier stage. Because maturation in plants is accelerated by drought stress, which results in decreased intra-cell material such as CP and feed quality (Buxton & Fales, 1994). It was also reported in other studies conducted on different fodder crops that drought causes a decrease in CP ratio (Kuchenmeister et al., 2013; Pecetti et al., 2016). When evaluated in terms of varieties, the highest leaf CP ratio was determined in Ultra, and the highest panicle CP content was determined in Helios variety. The different morphological and genetic structures of the varieties may have caused this.

As a matter of fact, it was reported by Svirskis (2003) that CP contents of the plant parts vary according to genetic characteristics in varieties of *A. cruentus* species grown under natural precipitation conditions, with the highest stem (7.1%), leaf (20.3%), and panicle (19.6%) CP ratios obtained from Raudonukai variety. In another study conducted by considering different plant densities, it was stated that CP ratios of leaves and stems in five genotypes belonging to two amaranth species varied between 15.3%–24.8% and 4.8%–9.5%, respectively (García-Pereyra, 2009).

It can be seen from Table 2 that, compared to other varieties, CP content of leaves, panicles, and stems of Helios variety grown in 2017 has shown a lower decrease under rainfed conditions in comparison with irrigated conditions. This may be the cause of the significance of triple interaction in terms of leaf, panicle, and stem CP. The highest leaf CP content was determined in Ultra variety (23.79%) grown under irrigated conditions in 2018, while the highest panicle (21.57%) and stem (13.73%) CP contents were determined in Helios variety grown under irrigated conditions in 2017 and 2018, respectively. These results showed that the leaf, panicle, and stem CP contents of the plants were higher under irrigated conditions compared to rainfed. As reported by Stordahl et al. (1999), different responses to agronomic conditions and annually changing climatic features by varieties with different genetic potential may be a reason for this result. In addition, the fact that 2017 was drier than 2018 and that plants grown under rainfed conditions mature at an earlier period compared to the irrigated conditions may have caused this situation.

Mean leaf, panicle, and stem NDF ratios of *Amaranth spp.* varieties planted under different growing conditions are included in Table 3. When Table 3 was examined, it was seen that the highest leaf, panicle, and stem NDF contents were determined in 2017. In terms of growing conditions, only the stem NDF ratio was found to be important and the highest ratio was determined in the rainfed. These differences may have been since 2017 was drier compared to 2018 and that the stress conditions were higher under rainfed conditions than the irrigated conditions. In addition, sowings were executed lately in 2017 in comparison to 2018. This resulted in more exposure of plants in 2017 to higher temperatures at earlier stages of development.

As a matter of fact, increasing temperature and drought accelerate the maturation of plants and this causes the formation of thick cell walls, thick cuticula, and highly lignified tissues within the plant (Buxton & Fales, 1994). Hence, it was reported by Svirskis (2003) that stem, leaf, and panicle (flower) NDF contents of varieties belonging to *A. cruentus* species vary and the highest stem (37.0%), leaf (14.0%), and panicle (26.9%) NDF ratios were obtained from Raudonukai variety. When evaluated in terms of varieties, the highest leaf (26.75%) and panicle (39.07%) NDF ratios were determined in Sterk, and the highest stem NDF ratio (46.64%) was determined in Ultra (Table 3). This may be due to the different genetic and morphological structures of the varieties. As a matter of fact, in previous studies, it was revealed that NDF contents of amaranths harvested as a whole plant vary between 13.8% and 47.0% according to growing conditions and varieties (Fazaeli et al., 2011; Písaríková et al., 2006; Pond & Lehmann, 1989; Sleugh et al., 2001). In the present study, it was observed that, except stem contents, leaf, and panicle NDF contents of amaranth varieties agreed with the literature and at the desired levels. As a matter of fact, it is desired to have NDF ratio below 40.0% in roughages (Rivera & Parish, 2010).

Effects of all binary interactions were found to be significant on the leaf, panicle, and stem NDF ratios (Figure 1).

Table 2.
The Changes in the Crude Protein (CP) Content of the Plant Parts According to Years, Growing Conditions, and Varieties (%)

Year	Variety	Leaf CP Ratio		Year Mean	Panicle CP Ratio		Year Mean	Stem CP Ratio		Year Mean
		Irrigated	Rainfed		Irrigated	Rainfed		Irrigated	Rainfed	
2017	Helios	17.97^{cd}	16.87^{d}	16.02^{b}	21.57^{a}	20.17^{b}	17.51	11.57^{cde}	10.67^{de}	10.05^{b}
	Sterk	17.23^{d}	12.43^{ef}		21.10^{ab}	13.70^{e}		11.43^{cde}	7.60^{g}	
	Ultra	18.03^{cd}	13.60^{e}		16.20^{d}	12.30^{f}		10.17^{ef}	8.87^{fg}	
2018	Helios	16.83^{d}	11.83^{f}	17.38^{a}	20.28^{ab}	16.91^{cd}	17.33	13.73^{a}	10.49^{de}	12.63^{a}
	Sterk	19.17^{bc}	13.29^{e}		16.12^{d}	11.76^{f}		13.52^{ab}	12.00^{bcd}	
	Ultra	23.79^{a}	19.38^{b}		21.37^{ab}	17.55^{c}		13.36^{ab}	12.66^{abc}	
GC mean		18.84^{a}	14.57^{b}		19.44^{a}	15.40^{b}		12.30^{a}	10.38^{b}	
Variety mean		Helios	15.87^{b}		Helios	19.73^{a}		Helios	11.62	
		Sterk	15.53^{b}		Sterk	15.67^{c}		Sterk	11.14	
		Ultra	18.70^{a}		Ultra	16.86^{b}		Ultra	11.26	

Note: a, b, c, d, e, f, g Values represented by the same letters do not differ statistically.
GC = growing condition.

Table 3.
The Changes in the Neutral Detergent Fiber (NDF) Contents of the Plant Parts According to Years, Growing Conditions, and Varieties (%)

Year	Variety	Leaf NDF Ratio		Year Mean	Panicle NDF Ratio		Year Mean	Stem NDF Ratio		Year Mean
		Irrigated	Rainfed		Irrigated	Rainfed		Irrigated	Rainfed	
2017	Helios	21.20	24.53	27.13[a]	37.00	37.00	39.89[a]	43.63	39.60	45.68[a]
	Sterk	28.43	32.00		41.37	41.63		45.43	45.57	
	Ultra	24.73	31.87		39.80	42.53		47.76	52.10	
2018	Helios	25.69	22.85	23.20[b]	39.13	35.51	35.42[b]	38.17	41.39	40.93[b]
	Sterk	26.13	20.42		36.97	36.30		36.29	43.03	
	Ultra	19.95	24.17		32.11	32.47		39.85	46.84	
GC mean		24.36	25.97		37.73	37.58		41.86[b]	44.75[a]	
Variety mean		Helios	23.57[b]		Helios	37.16[b]		Helios	40.70[c]	
		Sterk	26.75[a]		Sterk	39.07[a]		Sterk	42.58[b]	
		Ultra	25.18[ab]		Ultra	36.73[b]		Ultra	46.64[a]	

Note: [a,b,c]Values represented by the same letters do not differ statistically.
GC = growing condition.

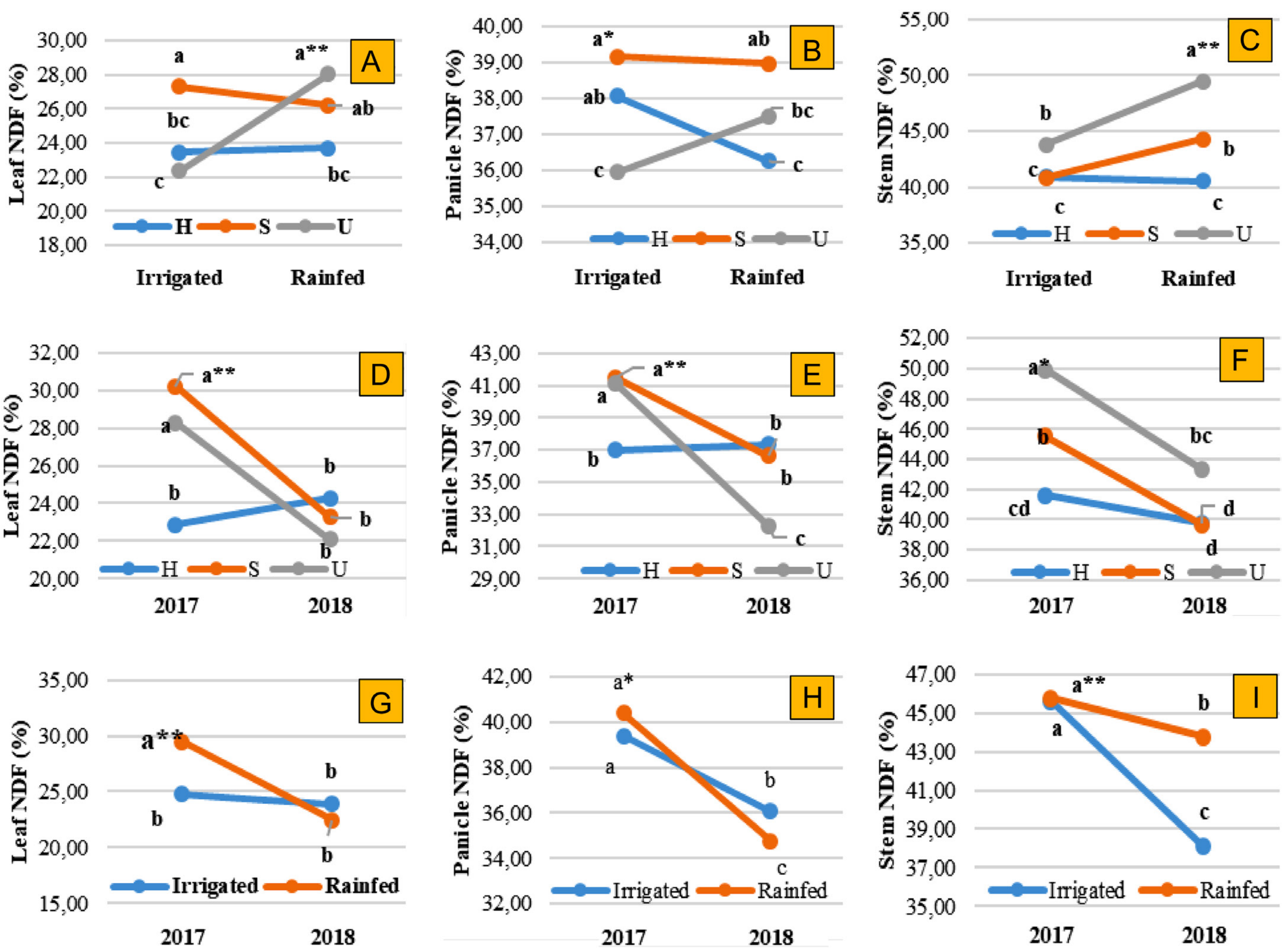

Figure 1.
*The Effect of Growing Condition × Variety (a, b, c), Year × Variety (d, e, f), and Year × Growing Condition (g, h, i) Interactions on the Leaf, Panicle, and Stem NDF. ** and * Plots Followed by Different Letters Are Significant at p ≤ .01 and p ≤ .05, respectively. H, Helios; S, Sterk; U, Ultra.*

The highest NDF contents in terms of growing condition × variety interaction were determined in Ultra grown under rainfed conditions and Sterk grown under irrigated conditions (Figure 1a), while the highest panicle and stem NDF ratio were detected in Sterk grown under irrigated conditions and Ultra grown under rainfed conditions, respectively (Figure 1b and c). These differences may have resulted from the differences in anatomical and chemical composition structures of the feed tissues due to variety and environmental conditions and due to varieties reaching harvest maturity at different dates. When evaluated in terms of year × variety interaction, while the leaf NDF content of Helios variety increased 6.12% in 2018 compared to 2017, Sterk and Ultra varieties were decreased by 22.97% and 21.54%, respectively (Figure 1d). When examined in terms of panicle NDF ratios, no change as to years in the panicle NDF content of Helios variety was observed, however, significant decreases were observed in panicle NDF ratios of the other two varieties in 2018 (Figure 1e). Finally, looking at stem NDF ratios, while a lower percentage of decrease (4.42 %) was observed in the stem NDF content of Helios in 2018 when compared to 2017, higher decreases were seen in stem NDF contents of Sterk (12.84%) and Ultra (13.20%) varieties (Figure 1f). These differences caused the year × variety of interaction to be significant, which may be due to differences in genetic structures of the varieties and to the fact that 2017 was drier than 2018. When evaluated in terms of year × growing condition interaction, the highest leaf NDF ratio was determined under rainfed conditions in 2017 (Figure 1g), while the highest panicle and stem NDF content were determined under rainfed and irrigated conditions in 2017 (Figure 1h and i). These differences may have been due to the fact that 2017 was drier compared to 2018 and that the stress conditions were higher under rainfed conditions than the irrigated conditions.

Mean leaf, panicle, and stem ADF ratios of *Amaranth spp*. varieties grown under irrigated and rainfed conditions are presented in Table 4. When Table 4 was examined, it was determined that the panicle and stem ADF ratios were higher in 2017 and the ADF content of the leaf and panicle in rainfed conditions. This may have been due to more water scarcity in 2017 and dry conditions. Because increasing drought stress accelerates the maturation of plants and, consequently, the increase of structural carbohydrates such as cellulose and hemicelluloses (Buxton & Fales, 1994). When evaluated in terms of varieties, it was determined that late varieties have higher leaf and panicle ADF and lower stem ADF content than the early variety Ultra (Table 4). As a matter of fact, since late-maturing varieties are exposed to higher temperatures than the early ones, their fiber content increases (Collins & Fritz, 2003).

When Table 4 was examined, it was observed that the ADF ratios of the varieties in leaf, panicle, and stem differed, and these rates were at the levels (under 31%) that should be in quality roughages (Rivera & Parish, 2010). It was also reported in another study conducted on different amaranth species and varieties that leaf and stem ADF contents varied between 17.4%–25.2% and 48.8%–59.4%, respectively (García-Pereyra, 2009). Moreover, it was also reported by Sleugh et al. (2001) and Olorunnisomo (2010) that ADF ratios varied between 16.8% and 32.9% in varieties belonging to *A. cruentus* and *A. hybridus* harvested as a whole plant at different stages of development. However, these results were higher than the findings of our study. These differences are thought to be caused by the differences in investigated varieties, regional climate conditions, and agronomic applications.

While the panicle ADF content of the Helios variety decreased in dry conditions according to the irrigated conditions, the panicle ADF rate of the Ultra variety increased (Figure 2a). This may be caused by the fact that the varieties reacted differently to growing conditions and that the Helios variety was later than Ultra. This has resulted in the significance of growing condition × variety interaction (Figure 2a). When year × variety interaction was evaluated in terms of panicle ADF ratio, the highest panicle ADF content was observed in Sterk sown in 2017, while the lowest content was observed in Ultra grown in 2018 (Figure 2b). Possible reasons for these findings may be the fact that the varieties reached harvest maturity on different dates and that 2017 was drier than 2018. Hence, Sterk is a late variety and Ultra is the earliest variety among the studied varieties. The highest leaf ADF content, which is important in terms of year × growing condition × variety interaction, was determined in Helios (12.45%) grown in rainfed conditions in 2018, and the highest stem ADF content was measured in Ultra (40.77%) cultivated under irrigated conditions in 2017 (Table 4). The fact that the leaves and stems of the varieties have different tissue organization according to the years

Table 4.
The Changes in the Acid Detergent Fiber (ADF) Contents of The Plant Parts According to Years, Growing Conditions, and Varieties (%)

Year	Variety	Leaf ADF Ratio		Year Mean	Panicle ADF Ratio		Year Mean	Stem ADF Ratio		Year Mean
		Irrigated	Rainfed		Irrigated	Rainfed		Irrigated	Rainfed	
2017	Helios	10.33^{de}	10.93^{bcd}	10.53	22.50	21.80	22.51^{a}	32.23^{bcd}	26.57^{gh}	33.17^{a}
	Sterk	11.10^{bc}	10.47^{cde}		23.77	24.23		33.73^{bc}	31.63^{cd}	
	Ultra	9.50^{f}	10.87^{cd}		20.17	22.60		40.77^{a}	34.07^{b}	
2018	Helios	9.97^{ef}	12.45^{a}	10.11	23.01	21.45	19.27^{b}	28.99^{ef}	27.92^{fg}	28.25^{b}
	Sterk	10.75^{cd}	11.64^{b}		18.87	19.13		31.00^{de}	24.64^{h}	
	Ultra	7.67^{h}	8.19^{g}		14.46	18.67		28.81^{efg}	28.13^{fg}	
GC mean		9.89^{b}	10.76^{a}		20.46^{b}	21.31^{a}		32.59^{a}	28.83^{b}	
Variety mean		Helios	10.92^{a}		Helios	22.19^{a}		Helios	28.93^{c}	
		Sterk	10.99^{a}		Sterk	21.50^{b}		Sterk	30.25^{b}	
		Ultra	9.06^{b}		Ultra	18.97^{c}		Ultra	32.94^{a}	

Note: $^{a, b, c, d, e, f, g}$ Values represented by the same letters do not differ statistically.
GC = growing condition.

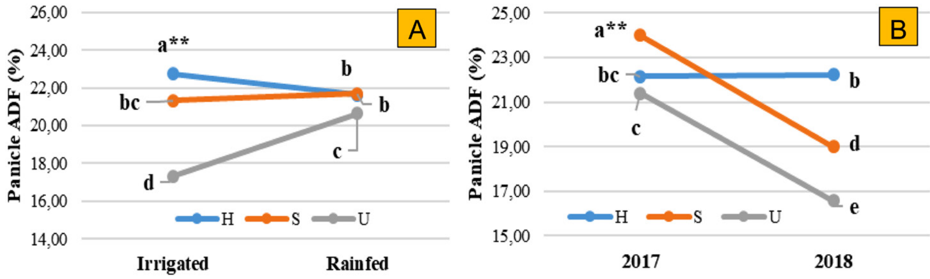

Figure 2
*The Effect of Growing Condition × Variety (a) and Year × Variety (b) İnteractions On The Panicle Acid Detergent Fiber (ADF). **Plots Followed by Different Letters Are Significant at p ≤ .01. H, Helios; S, Sterk; U, Ultra.*

and growing conditions (Önal Aşcı & Acar, 2018) may have caused this. In addition, it may be due to the fact that Helios is a late variety compared to other varieties and that there are more stress conditions under rainfed.

Dry matter digestibility and metabolic energy contents are calculated considering ADF ratios of the feed. According to this calculation, feeds with higher ADF content have lower DMD and ME values, and vice versa. It was also seen in this study that leaf, panicle, and stem DMD-ME contents were in compliance with the ADF values. As a matter of fact, when Table 4 was examined, it was determined that 2018, which has a lower panicle and stem ADF ratio, had a higher DMD (Table 5) and ME content (Table 6) compared to 2017.

Similarly, irrigated conditions with lower leaf and panicle ADF ratio had higher DMD (Table 5) and ME content (Table 6) than rainfed ones and dry conditions with lower stem ADF ratio than irrigated conditions. Because drought stress causes an increase in lowly digestible fractions such as cell walls and a decrease in easily digestible compounds such as non-structural carbohydrates and CP (Önal Aşcı and Acar, 2018). Hence, it was expressed that the forage plants grown in dry conditions had a thicker layer of cutin on the epidermis compared to those grown in the cool season and, therefore, their digestibility decreased (Hatfield et al., 2007).

When evaluated in terms of varieties, the highest leaf and panicle DMD-ME content was determined in Ultra, which is the early variety, and the stem DMD-ME value was determined in Helios, which is a late variety. This might be caused by Ultra being an early variety, compared to other varieties in the research, which reached harvesting maturity at an earlier date. Early maturing varieties will have lower fiber content and higher amount of structural carbohydrates compared to late varieties since they are exposed shorter to higher temperatures (Collins & Fritz, 2003). In a study conducted with amaranth species under rainfed conditions, stem, leaf, and panicle (flower) DMD contents of varieties were reported to vary between 57.5%–62.2%, 70.4%–71.0%, and 58.5%–60.9%, respectively (Svirskis, 2003). It was reported in another study that *A. hypochondriacus*, which was harvested as a whole plant at the beginning of flowering under irrigated conditions, had a content of 2.82 Mcal/kg ME (Fazaeli et al., 2011). In this study, it was also observed that ME and DMD of the varieties of amaranth species varied according to plant parts. Metabolic energy and dry matter digestibility contents were found to be sufficient and the findings were in agreement with the literature.

In the present study, panicle DMD and ME contents were found to be significant in terms of growing condition × variety interaction (Figure 3a and b). While panicle DMD and ME contents of Ultra and Sterk varieties were decreased under rainfed conditions compared to irrigated conditions, the DMD and ME contents of Helios variety also increased, which resulted in the significance of growing condition × variety interaction. This may be caused by Helios being a late variety and due to existence of more stress factors under rainfed conditions.

When examined in terms of year × variety interaction, panicle DMD and ME contents of Helios did not show a significant difference as to years, however, a significant increase was observed in

Table 5.
The Changes in the Dry Matter Digestibility (DMD) of the Plant Parts According to Years, Growing Conditions, and Varieties (%)

		Leaf DMD		Year	Panicle DMD		Year	Stem DMD		Year
Year	Variety	Irrigated	Rainfed	Mean	Irrigated	Rainfed	Mean	Irrigated	Rainfed	Mean
2017	Helios	80.87^cd	80.40^def	80.70	71.36	71.93	71.37^b	63.78^efg	68.20^ab	63.06^b
	Sterk	80.24^ef	80.76^cde		70.39	70.02		62.65^fg	64.26^ef	
	Ultra	81.49^b	80.43^de		73.19	71.31		57.14^h	62.35^g	
2018	Helios	81.13^bc	79.20^g	81.02	70.98	72.19	73.89^a	66.31^cd	67.15^bc	66.89^a
	Sterk	80.53^de	79.83^f		74.20	74.00		64.75^de	69.71^a	
	Ultra	82.92^a	82.26^ab		77.64	74.36		66.46^bcd	66.98^bc	
GC mean		81.20^a	80.52^b		72.96^a	72.30^b		63.52^b	66.44^a	
Variety mean		Helios	80.40^b		Helios	71.62^c		Helios	66.36^a	
		Sterk	80.34^b		Sterk	72.15^b		Sterk	65.34^b	
		Ultra	81.84^a		Ultra	74.12^a		Ultra	63.23^c	

Note: ^a, b, c, d, e, f, g, h Values represented by the same letters do not differ statistically.
GC = growing condition.

Table 6.
The Changes in the Metabolic Energy (ME) Contents of the Plant Parts According to Years, Growing Conditions, and Varieties (Mcal/kg)

		Leaf ME			Panicle ME		Year	Stem ME		Year
Year	Variety	Irrigated	Rainfed	Year Mean	Irrigated	Rainfed	Mean	Irrigated	Rainfed	Mean
2017	Helios	3.06^{cd}	3.05^{de}	3.06	2.73	2.75	2.73^{b}	2.46^{efg}	2.62^{ab}	2.44^{b}
	Sterk	3.04^{ef}	3.06^{cd}		2.69	2.68		2.42^{fg}	2.48^{ef}	
	Ultra	3.09^{b}	3.05^{de}		2.79	2.73		2.23^{g}	2.42^{fg}	
2018	Helios	3.07^{bc}	3.00^{g}	3.07	2.71	2.76	2.82^{a}	2.55^{cd}	2.58^{bc}	2.57^{a}
	Sterk	3.05^{de}	3.03^{f}		2.83	2.82		2.50^{de}	2.67^{a}	
	Ultra	3.13^{a}	3.11^{ab}		2.95	2.83		2.56^{cd}	2.58^{bc}	
GC mean		3.08^{a}	3.05^{b}		2.79^{a}	2.76^{b}		2.45^{b}	2.56^{a}	
Variety mean		Helios	3.05^{b}		Helios	2.74^{c}		Helios	2.55^{a}	
		Sterk	3.04^{b}		Sterk	2.76^{b}		Sterk	2.52^{b}	
		Ultra	3.10^{a}		Ultra	2.83^{a}		Ultra	2.45^{c}	

Note: $^{a, b, c, d, e, f, g}$ Values represented by the same letters do not differ statistically.
GC = growing condition.

DMD and ME contents of Sterk and Ultra in 2018 (Figure 3c and d), which resulted in the significance of year × variety interaction. The fact that 2018 was a cooler year than 2017 and Ultra being an early variety compared to others may be accounted for as other causes behind this finding. The highest leaf DMD (82.92%) and ME (3.13 Mcal/kg) content, which are important in terms of year × growing condition × cultivar interaction, were determined in the Ultra variety grown under irrigated in 2018, and the highest stem DMD (69.71%) and ME (2.67 Mcal/kg) content in the Sterk variety grown under rainfed conditions in 2018 (Tables 5 and 6). The fact that leaf and stems have different tissue organization as to years and growing conditions may be a cause of this situation. Hence Stordahl et al. (1999) reported that vegetable-type amaranths had a more succulent body and leaf structure, and thus a higher digestibility than the grain-type amaranths harvested during the same period. In addition, DMD of the amaranths harvested as whole plants was reported to vary between 59.0% and 79.0% according to the growing conditions, development periods, species, and varieties (Fazaeli et al., 2011; Olorunnisomo, 2010; Rahnama & Safaeie, 2017; Sleugh et al., 2001).

Mean relative feed values of plant parts (leaf, panicle, and stem) according to years, growing conditions, and varieties are presented in Table 7. When Table 7 was examined, RFV of leaves, panicles, and stems was found higher in 2018 compared to 2017.

This may be due to the lower NDF and ADF ratios in 2018 compared to 2017 (Tables 3 and 4). When evaluated in terms of varieties, the highest leaf RFV was found in Helios (319.1) and Ultra

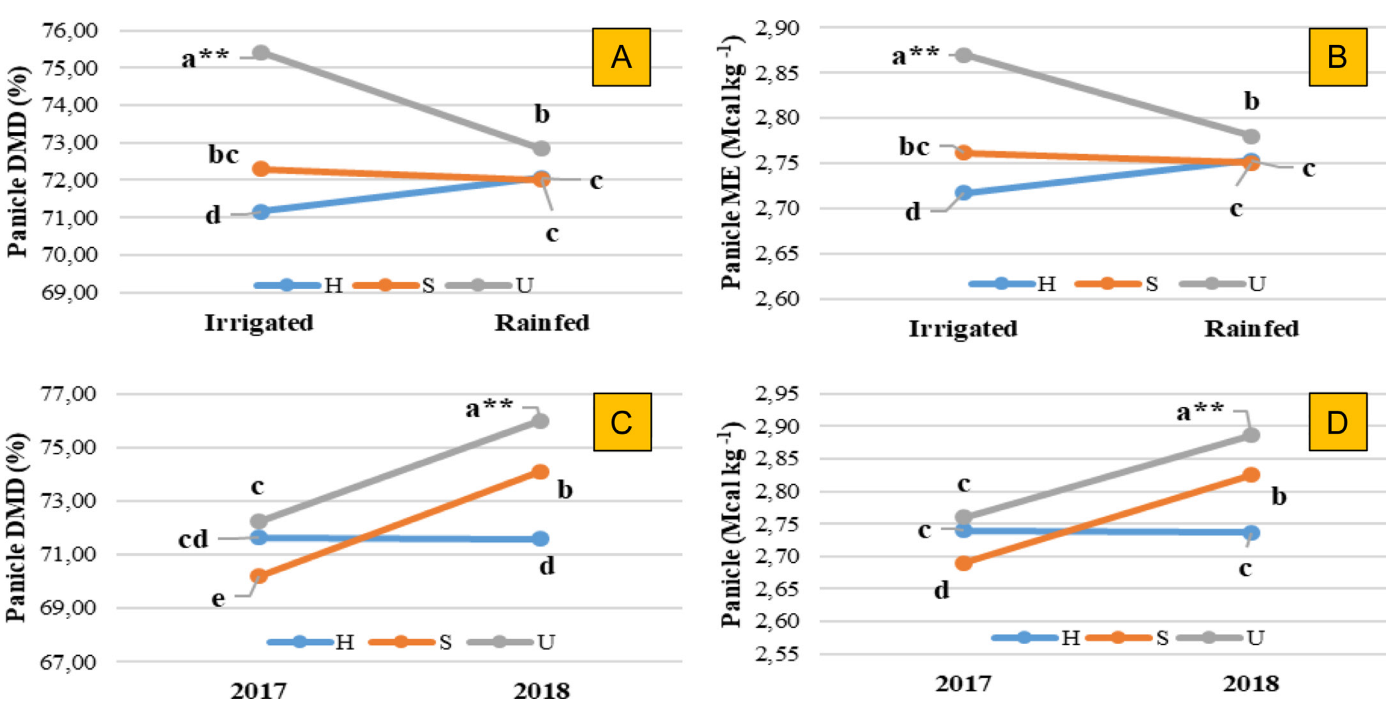

Figure 3
The Effect of Growing Condition × Variety (a-b) and Year × Variety (c-d) Interactions on Panicle Dry Matter Digestibility (DMD) and Metabolic Energy (ME).
***Plots Followed by Different Letters Are Significant at p ≤ .01. H, Helios; S, Sterk; U, Ultra.*

Table 7.
The Changes in the Relative Feed Values (RFV) of the Plant Parts According to Years, Growing Conditions, and Varieties

Year	Variety	Leaf RFV Irrigated	Leaf RFV Rainfed	Year Mean	Panicle RFV Irrigated	Panicle RFV Rainfed	Year Mean	Stem RFV Irrigated	Stem RFV Rainfed	Year Mean
2017	Helios	355.2^{ab}	304.9^{c}	284.5^{b}	179.6	180.9	167.1^{b}	136.0	160.2	129.7^{b}
	Sterk	262.9^{de}	235.5^{e}		158.3	156.4		128.3	131.2	
	Ultra	306.4^{c}	242.2^{e}		171.0	156.4		111.3	111.4	
2018	Helios	293.9^{cd}	322.7^{bc}	329.4^{a}	169.0	189.3	195.5^{a}	161.7	150.9	153.3^{a}
	Sterk	286.8^{cd}	364.2^{a}		186.8	189.9		167.9	150.7	
	Ultra	386.8^{a}	322.1b^{c}		225.1	213.1		155.4	133.2	
GC mean		315.3	298.6		181.6	181.0		143.4	139.6	
Variety mean		Helios	319.1^{a}		Helios	179.7^{b}		Helios	152.2^{a}	
		Sterk	287.3^{b}		Sterk	172.8^{c}		Sterk	144.5^{b}	
		Ultra	314.4^{a}		Ultra	191.4^{a}		Ultra	127.8^{c}	

Note: ^{a,b,c}Values represented by the same letters do not differ statistically.
GC = growing condition.

(314.4) and the highest panicle (191.4) and stem (152.2) RFV in Ultra and Helios varieties, respectively (Table 7). Differences in leaf, panicle, and stem tissue organization of the cultivars may have caused this. As a matter of fact, the chemical structure of the intracellular and cell walls (NDF and ADF) differs significantly depending on the tissue type and plant species (Zeng et al., 2017). These results obtained in the present study were found to be higher than the RFV (157.1–171.5) determined for amaranth species and varieties harvested as whole plants reported by Rahnama and Safaeie (2017). It is thought that this is caused by the differences in investigated varieties, regional climate conditions, and agronomic applications. As a result, these differences between years and varieties are thought to be caused by the NDF and ADF contents of the plant parts. Because RFV is calculated by using ADF and NDF values of the feed (Moore & Undersander, 2002). Therefore, the high NDF and ADF ratios decrease the RFV of the feed and vice versa.

Looking at Figure 4a, while panicle RFV of Sterk variety was found to be not differ according to irrigated and rainfed conditions, panicle RFV of Helios decreased under irrigated conditions in comparison to rainfed conditions and the panicle RFV of Ultra variety increased.

When evaluated in terms of stem RFV, while the stem RFVs of Sterk and Ultra varieties were decreased under rainfed conditions compared to the irrigated conditions, the stem RFV of the Helios cultivar increased (Figure 4b). This caused the panicle and stem RFV to be important in terms of growing condition × cultivar interaction. When analyzed in terms of year × variety interaction, it was seen that the panicle and stem RFV of Helios variety

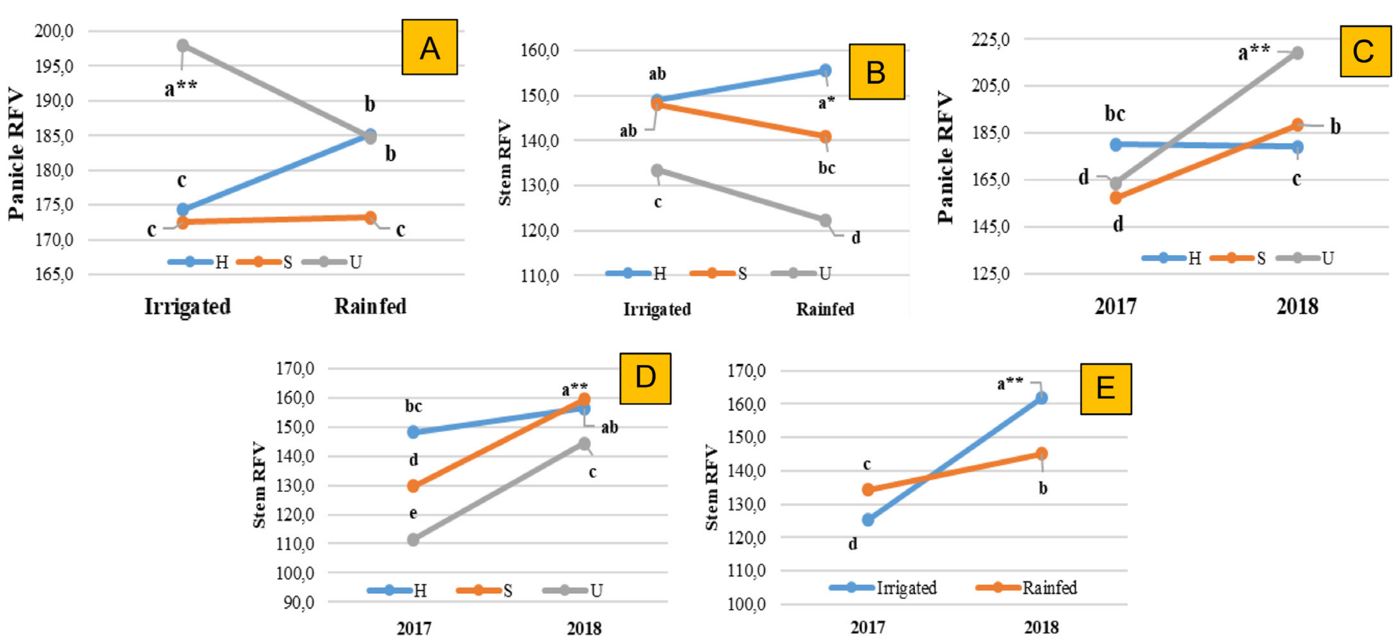

Figure 4
*The Effect of Growing Condition × Variety (a, b), Year × Variety (c, d), and Year × Growing Condition (e) Interactions on the Panicle and Stem Relative Feed Value. ** and *Plots Followed by Different Letters Are Significant at p ≤ .01 and p ≤ .05, respectively. H, Helios; S, Sterk; U, Ultra.*

does not vary as to years, while the panicle RFVs of Sterk and Ultra varieties increased significantly in 2018 (Figure 4c and d). Besides the varieties reacting differently to the growing conditions and climatic conditions that change according to years, the fact that 2017 was drier compared to 2018 and the existence of more stress factors under rainfed conditions may have caused this outcome. Because the late varieties will be exposed to higher temperatures longer than the early ones, their fiber content (NDF and ADF ratios) increases (Collins & Fritz, 2003). Similarly, increasing drought stress (under rainfed and in 2017) causes an increase in less digestible fibrous compounds (NDF and ADF), such as the cell wall in plants (Önal Aşcı & Acar, 2018). As a result, RFV of the panicle and stem decreases because of increasing NDF and ADF contents. In addition, the fact that 2018 was cooler compared to 2017 and the stress conditions were less in irrigated conditions than in dry conditions caused the year × growing condition interaction to be significant in terms of stem RFV (Figure 4e). As a matter of fact, plants in cool conditions with less stress factors have thinner cell walls and more intracellular substances (Hatfield et al., 2007; Önal Aşcı & Acar, 2018). Thus, the quality of the feed, and therefore the stem RFV, increases under such conditions. The leaf RFV was found to be significant in terms of year × growing condition × variety interaction, and the highest leaf RFV was determined in the Ultra (386.8) cultivated under irrigated conditions and Sterk (364.2) cultivated under rainfed conditions in 2018, whereas the lowest leaf RFV was detected in Sterk (235.5) and Ultra (242.2) varieties grown under rainfed conditions in 2017 (Table 7). This may be a result of 2017 being a drier year compared to 2018 and the existence of more stress factors under rainfed conditions. In addition, carrying out sowings at a later date in 2017 compared to 2018 caused plants to be exposed to higher temperatures during their early development stages.

Conclusion and Recommendation

As a result, the feed quality characteristics of the plant parts (leaf, panicle, and stem) of the amaranth varieties that were studied differed significantly according to the climatic and growing conditions. According to the 2-year means, the leaves of Helios and Sterk varieties, panicle of Sterk variety, and the stem quality values of Ultra and Helios varieties were the least varied according to growing conditions. In addition, considering the RFV, which is the indicator of feed quality, Ultra variety was observed to react more to changing climate conditions, with respect to other types. In addition, it was revealed that the leaves and panicles of the examined varieties produced a higher quality feed material under irrigated conditions but their stems (except CP) under rainfed conditions. As a result, it has been revealed that plant parts of Amaranth varieties can be a good alternative protein and fiber source in animal nutrition.

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