TÜBİTAK

Turkish Journal of Agriculture and Forestry

http://journals.tubitak.gov.tr/agriculture/

Research Article

Turk J Agric For
(2020) 44: 533-542
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doi:10.3906/tar-1912-58

Effect of morphological components on the herbage yield and quality of quinoa (*Chenopodium quinoa* Willd.) grown at different dates

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Received: 24.12.2019 • **Accepted/Published Online:** 19.05.2020 • **Final Version:** 02.10.2020

Abstract: In addition to environmental conditions and cultural practices, plant factors, particularly morphological parts, have a significant effect on the yield and feed value of roughages. However, no studies have been conducted for this purpose on quinoa grown for hay production. Therefore, between 2017 and 2018, a study was planned to determine the effect of different sowing times (mid-March, late March, early April, and mid-April) and plant parts (leaves, stems and panicles) together on the herbage yield and quality characteristics of quinoa. In the experiment established according to a randomized complete blocks design, a significant decrease in plant height, stem thickness, number of branches, and panicle ratios were determined with delayed sowing time. The highest contribution of the stems to the fresh herbage and dry matter yield was determined in the 1st sowing period, but the highest contribution to the neutral detergent fiber, acid detergent fiber and acid detergent lignin contents were determined in the first 2 sowing periods. The highest crude protein ratio and yield were determined in the leaves in the late and 1st sowing period, respectively. The highest digestible dry matter and metabolic energy contents were measured in the leaves in all of the sowing periods. The highest digestible energy and relative feed values were determined in the leaves of plants sown in the last 2 sowing periods. As a result, it was shown that the leaves had a positive contribution to the feed quality of quinoa, while the stems had a positive contribution to the feed yield. In addition, it was concluded that sowing should be performed without delay for high yield and at a later time for quality hay production.

Key words: *Chenopodium quinoa*, feed yield and quality, Iğdır, plant parts

1. Introduction

Quinoa (*Chenopodium quinoa* Willd.), which is also known as pseudo-grain, is an annual plant that has been cultivated for thousands of years in the Andes (Cusack, 1984). The seeds of quinoa are rich in protein, minerals, carbohydrates, and antioxidant compounds when compared to cereals, such as corn, oats, rice, and wheat (Repo-Carrasco et al., 2011; Stikic et al., 2012; Ruiz et al., 2014), and they are usually utilized as human food (Bhargava et al., 2007). Therefore, quinoa has been evaluated in terms of its seed performance in most of the previouslyconducted scientific studies (Geren et al., 2014; Katsunori et al., 2016; Kır and Temel, 2016; 2017; Tan and Temel, 2017a; Tan and Temel, 2018; Casini, 2019). However, the nutritional value of quinoa hay is quite high (Bhargava et al., 2006; Peterson and Murphy, 2015; Tan and Temel, 2017b), and the aboveground parts (whole plant) are also preferred as animal feed (Galwey, 1989). Its leaves can be fed to sheep, goats, and cattle or used for silage (Peterson and Murphy, 2015). Hence, it was shown in research conducted in Denmark that quinoa, which has a high yield and protein content, can indeed be a valuable forage crop for dairy farms through ensilation (Darwinkel and Stølen, 1997).

In order to achieve high performance in animal production, the quantity and quality of feed provided to animals should be appropriate. This can be achieved by appropriate cultivation techniques that are suitable for local environmental conditions. As a matter of fact, environmental factors, plant characteristics, and cultural practices are important factors that affect the yield and feeding value of plants grown as forage sources (Önal Aşcı and Acar, 2018). When evaluated in terms of environmental conditions, quinoa, unlike many cultivated plants, is able to adapt well to extreme climatic and soil conditions without losing much yield and quality (Bhargava et al., 2006; Fuentes and Bhargava, 2011; Fuentes et al., 2012; Abtahi Adolf et al., 2013; Ruiz et al., 2014). However, in order to obtain high yield and quality performance from quinoa, it is important to have complete knowledge of cultural practices such as the sowing time,according to the regions, as soon as possible. This is because the sowing time

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is one of the main factors that plays an important role in the development of production technologies and increases productivity in quinoa (Rauf et al., 2010; Sajjad et al., 2014; Shoman, 2018). As a matter of fact, in studies conducted under different climatic conditions, it has been shown that sowing times have an important effect on the yield and quality characteristics of quinoa (Ujiie et al., 2007; Hirich et al., 2014; Awadalla and Morsy, 2017). However, such studies in Turkey on the extension and increase of quinoa production, which has rather recently been understood by the Turkish public, are almost nonexistent.

Plant characteristics (species, varieties, developmental periods, plant organs, and regrowth) should be well known in order to improve the yield and quality characteristics of plants grown as forage sources in animal nutrition. Among these factors, the morphological (vegetative) parts of the plants, depending on the sowing and harvesting times, have a great effect, since there is generally an increase in herbage yield and a decrease in nutritional value as the stem/leaf ratio of the plants increases (Önal Aşcı and Acar, 2018). Hence, it has been shown in few studies conducted on cultivated forage species that the stems have more crude fiber content than the leaves, and they have at least 2–3 times less protein content and digestibility. It was also stated that the stems of plants grown as feed sources have a much higher lignin content than the leaves (Gülümser and Acar, 2012; Keleş, 2014; Önal Aşcı and Acar, 2018). However, there have been no studies on how extensively the leaves, stems, and panicles of quinoa contribute to the feed yield and nutrient content.

In this study, the effect of different sowing times and plant parts on the yield and nutritional content of quinoa were aimed to be revealed together. For this purpose, the leaves, stems, and panicles of quinoa sown at 4 different periods were tested by harvesting when the plants reached the fruiting stage.

2. Materials and methods

This study was conducted under irrigated conditions in Iğdır Province, located in northeastern Turkey, between 2017 and 2018. When some meteorological data of the research area were examined, the total rainfall amounts of the growing seasons of 2017 and 2018 were measured as 100.0 and 141.7 mm, relative humidity as 47.9% and 52.8%, and average temperatures as 18.2 and 19.5 °C, respectively. According to the long-term average, the average temperature, relative humidity, and total precipitation were measured as 18.4 °C, 48.6%, and 166.4 mm, respectively (Table 1) (MGM, 2019). According to these data, the experiment was conducted under relatively more arid conditions, since lower precipitation was observed according to the long-term averages in the cultivation period within which the research conducted. Adequate amounts of soil samples (0–30 cm) were taken in both research years and according to the results of the analyses, it was found that soils were nonsaline and slightly alkaline, with mild lime contents, low available phosphorus levels, and high potassium contents. However, the experiment site in 2017 had a clay-loam soil structure with a good organic matter content, while the 2018 research site was classified as clay soil with medium-level organic matter contents (Table 2) (Kacar, 2012).

In the adaptation study conducted with 14 varieties over 2 years, Mint Vanilla cultivar of quinoa (*Chenopodium quinoa* Willd.) with the highest hay yield was used as plant material (Tan and Temel, 2017b). In this study, 4 different sowing times at 10-day intervals were tested. Accordingly, in 2017, the 1st (SD_1), 2nd (SD_2), 3rd (SD_3), and 4th (SD_4) sowings were conducted on March 15th and 25th, and April 5th and 15th, respectively. In 2018, SD_1 was conducted on March 16th, SD_2 on March 27th, SD_3 on April 7th, and SD_4 on April 19th. In order to reveal the effect of the morphological parts (leaves, stems, and panicles) on the quantity and quality of the hay, the plants were harvested when they reached the fruiting stage. This stage of sampling is the time when all of the panicles in the plant have completed flowering and formed fruits. The reason why this stage is preferred is that the yields still increase linearly in the harvests in full flowering stages (Yolcu, 2018).

The research was designed according to a randomized complete block design with 3 replicates. The hole sowing method was used for sowing. Seeds were sown into the plots, at 7.35 m^2 (3 m × 2.45 m), into furrows opened by a marker into mellowed soil at a sowing depth of 1.5–2.0 cm with 35-cm row spacing and 15-cm intrarow spacing (plant-to-plant distance). The soil was fertilized with 75 kg of pure N (21% ammonium sulphate) and 80 kg of pure P_2O_5 (39%–41% triple super phosphate) per hectare during the preparation of the seedbeds. Moreover, an additional 5 kg of pure N per hectare was also applied when plant heights reached 30–40 cm (Geren, 2015). Soil humidity was measured using a soil water potential device and the plants were irrigated when 50% of the field capacity was depleted. A sufficient amount of water was given to the plants by drip irrigation until the field regained capacity. Weeds formed between the plots and blocks were controlled by pulling and hoeing, and this process was repeated 3 times during the growth of the plants. In addition, insecticide was applied to insects seen at the 2–4 leaf stage.

In both years, since sowing was conducted on different dates, the harvests took place on different dates. Accordingly, plots sown on SD_1, SD_2, SD_3, and SD_4 were harvested on June 19th, 21st, 24th, and 26th of 2017 and on June 25th, 28th, and 30th and July 2nd of 2018, respectively. When all of the plants reached the milking

Table 1. Some climatic characteristics of the research area*.

Months	Temperature (°C)			Precipitation (mm)			Relative humidity (%)		
	LTA**	2017	2018	LTA	2017	2018	LTA	2017	2018
March	8.5	6.7	12.3	19.0	11.4	16.5	47.7	59.9	51.9
April	14.4	13.4	14.2	43.9	18.1	18.2	50.5	47.2	49.6
May	18.4	18.6	18.4	57.2	57.0	69.3	56.2	54.0	65.5
June	23.6	24.2	23.4	30.5	8.2	31.8	46.1	42.9	54.5
July	26.9	28.0	29.2	15.8	5.3	5.9	42.7	35.4	42.4
Total/mean	18.4	18.2	19.5	166.4	100.0	141.7	48.6	47.9	52.8

*MGM, 2019; ** Long-term average.

Table 2. Some chemical and physical properties of the study area soils.

Years	Texture class	Organic matter (%)	$CaCO_3$ (%)	EC (dS/m)	pH	P_2O_5 (kg/da)	K_2O (kg/da)
2017	Clay-loam	1.80	8.87	1.92	7.90	3.50	383.9
2018	Clay-loam	2.00	9.00	1.80	7.95	1.53	356.2

stage, the parts remaining in the harvest area (3.5 m^2) were cut, and then their fresh weights were weighed by separating them from the leaves, stems, and panicles. The plant parts whose fresh weights were determined were first dried in the open air, and then dried in an oven at 70 °C until a constant weight was obtained and the dry matter yields (DMYs) were determined. Next, the leaf, stem and panicle ratios were determined by proportioning the weights of the plant parts to total plant weight. In addition, the plant height (cm), stem thickness (mm), and number of branches was determined by selecting 10 random plants from the harvest area before the harvest. The N content of the samples, which were dried and ground (to 1 mm in diameter) separately, were determined using the method of Kjeldahl and the resulting N% was multiplied by the coefficient of 6.25 to calculate the crude protein ratios (CPRs) (AOAC, 1997). Next, the CPRs were multiplied by the DMYs to determine the crude protein yields(CPYs). Neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) contents were determined according to the method developed by Van Soest et al. (1991). Dry matter digestibility (DMD) of the feed samples was determined by the method suggested by Sheaffer et al. (1995), as DMD% = ((88.9 – (0.779 × ADF%)), and the digestible energy (DE) was calculated with the formula developed by Fonnesbeck et al. (1984) (DE Mcal/kg = 0.27 + 0.0428 ×DMD%). The metabolic energy (ME) content was based on the equation (ME Mcal/kg = 0.821 × DE) formulated by Khalil et al. (1986), while the relative feed value (RFV) was calculated by the equation (RFV = (DMD×DMI) / 1.29) developed by Sheaffer et al. (1995). In order to determine the dry matter intake (DMI) in this formula, the equation DMI% = 120 / NDF% was used.

The obtained data were analyzed using the JMP 5.1 statistical package program (SAS Institute, Cary, NC, USA). Plant heights, stem thicknesses, number of branches, leaf, stem, and panicle ratios of the quinoa were determined according to the randomized complete block design, while variance analyses of the parameters examined for the years, sowing times, and plant parts were performed in a factorial arrangement of a completely randomized block design repeated in each year. The $LSD_{(0.05)}$ test was used to compare the averages of the results.

3. Results and discussion

In this study, conducted over2 years, the plant heights, stems thicknesses, number of branches, and panicle ratios of quinoa showed differences in terms of the sowing times. The highest plant height and number of branches were determined in plants sown on SD_1 and SD_2, but the highest panicle ratio was determined in those sown on SD_1 and the highest stem thickness was in those sown on SD_1–SD_3 (Table 3). In other words, as the sowing time was delayed, significant decreases were observed in the examined parameters. This may have been due to the fact that the plants benefitted less from environmental conditions, such as water, light, and nutrients, in the later sowings when compared to the early sowings, and thus were less

Table 3. Some morphological characteristics of quinoa according to the sowing time and years.

		Plant height (cm)	Stem diameter (mm)	Branch number (number/plant)	Leaf rate (%)	Stem rate (%)	Panicle rate (%)
Mean year	2017	149.8	14.3	22.7	32.0	43.5	25.0
	2018	153.6	14.0	23.1	31.7	43.3	24.9
Mean sowing time	SD_1	164.6 a	14.9 a	24.0 a	29.1	44.3	26.6 a
	SD_2	161.8 a	14.4 a	24.1 a	32.4	44.0	23.6 b
	SD_3	150.7 b	14.2 a	22.9 b	30.9	43.4	25.7 ab
	SD_4	129.6 c	12.2 b	20.5 c	35.1	41.9	24.0 b
$LSD_{(0.05)}$		$_{SD}$: 6.02**	$_{SD}$: 0.92**	$_{SD}$: 0.80**	ns	ns	$_{SD}$: 1.5*

**P < 0.01; *P < 0.05; ns: Nonsignificant. Values represented by the same letters were not different. SD: Sowing date.

able to produce organic matter. Moreover, insufficient vegetative growth (plant height, stem thickness, number of branches) due to increasing air temperatures in the late sowing period may have been another reason of this finding. Because an increase in temperature accelerates ripening, the stem diameter decreases and shortens the plant height of plants[1],[2]. Hence, it was reported in previous studies conducted with quinoa that significant decreases were observed in the plant height, stem thickness, number of branches, and panicle ratios with the progress of sowing time (Hirich et al., 2014; Sajjad et al., 2014; Ramesh, 2016; Yolcu, 2018).

In the second part of the study, the effects of the year, sowing time, and plant parts on the feed yield and quality of quinoa were tested. As a result of the statistical analyses, no significant effects of the year and triple interactions were found on the yield and quality. However, since binary interactions were significant for all of the studied parameters, the main factors were not considered separately, and the presentation of data and discussion were made according to the sowing time × plant part interaction, which was significant.

The effect of the sowing time × plant part interaction on the fresh herbage yield (FHY) and DMYs of quinoa was significant, at 1%. The highest FHY (39,486 kg ha^{-1}) and DMY(8376 kg ha^{-1}) were obtained from the stems of plants sown on SD_1, while the lowest values were obtained from the panicles of those that were sown on SD_4 (12,625 kg ha^{-1} and 2311 kg ha^{-1}, respectively) (Figures 1a and 1b). These results showed that there were significant reductions in yields in all of the plant parts with the delay in sowing time. This may have been due to the increase in air temperatures and the limited time available for the plants to benefit from the environmental conditions, especially in the late sowings, because the FHYs and DMYs of plants vary according to environmental conditions and the length of the growing season (Tan and Temel, 2012; Önal Aşcı and Acar, 2018). It was stated by Bertero et al. (2000) that high temperatures and short-day conditions cause low leaf formation in quinoa plants. It was reported in another study that the highest leaf, stem, and panicle DMYs in quinoa were obtained from early sowings, while the lowest values were obtained from late sowings (Ramesh, 2016).

This study also showed that the contribution of the stem to the FHYs and DMYs was higher than those of the leaves and panicles at all of the sowing times (Figures 1a and 1b), because the formation of structural carbohydrates, which are extracellular substances, are more common in stems than in other plant parts. However, it was reported by Ramesh (2016) that the leaves had higher DMYs than the panicles and stems, as seen in their plants from the 1st sowing (October 15), while when compared to the stems and leaves,the panicles of plants from their 2nd (November 1) and 3rd (November 16) sowings had higher DMYs. In addition, it was revealed that the stems of plantsfrom their 2nd and 3rd sowings had more dry matter than the leaves. These results were not similar to the current findings. It can be said that the variety used, degree of latitude at which the trial was conducted, and differences in the harvesting period may be the causes underlying the disagreement of the findings. In terms of the FHY, the stem and panicle yields were decreased by 10.92% and 0.30%, respectively, in plants sown on SD_2 when compared with those sown SD_1, while the leaf yield increased by 6.99% (Figure 1a). This resulted from the significance of the binary interaction. In terms of the DMY, while there was a continuous decrease in the stem and panicle yields, the fact that the leaf yield values were in the same statistical group as those in plants

[1] Buxton DR (1995). Growing quality forages under variable environmental conditions [online]. Website http://pss.uvm.edu/pdpforage/Materials/ForageQuality/Growing_Quality_Forages_under_Variable_Environmental_Conditions_Buxton.pdf [accessed 20 December 2019].

[2] Rankin M (1997). Temperature and moisture effects on forage quality [online]. Website https://fyi.extension.wisc.edu/forage/temperature-and-moisture-effects-on-forage-quality/ [accessed 22 December 2019].

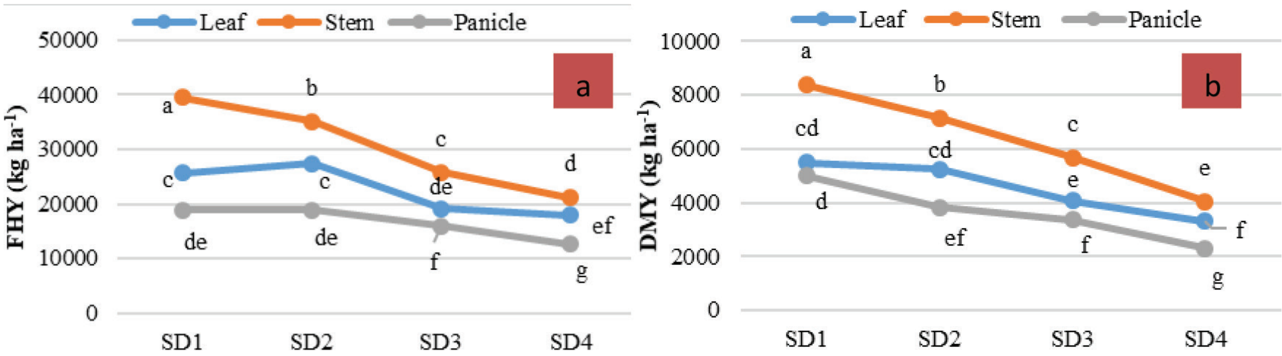

Figure 1. Effects of the sowing date × plant part interaction on the fresh herbage yield (FHY) and dry matter yield (DMY). Plots represented by different letters were significant at P ≤ 0.01. SD: Sowing date.

sown on SD_1 and SD_2, and then showed a decline, may have caused the binary interaction to be significant (Figure 1b).

In terms of the crude protein content and yield, the sowing time × plant part interaction showed significant differences (P ≤ 0.01). According to this, the highest crude protein content was measured in the panicles (22.63%) and leaves (22.50%) of plants sown in the late period, but the lowest value (6.98%–8.02%) was measured in the stems at all of the sowing times (Figure 2a). This may have been due to the reduced stem/leaf ratio as a result of the poor growth of the stems as the sowing time was delayed, as well as differences between the tissues in the leaves, stems, and clusters. In general, leaves have more photosynthetic tissue and thin-walled mesophyll cells, which are rich in intracellular substances, than the stem[3] (Buxton and Redfearn, 1997; Fales and Fritz, 2007). Hence, Buxton (1996) stated that quinoa leaves were richer in protein than their stems. Moreover, seeds, which are rich in nonstructural carbohydrates, are found in the panicles. As a matter of fact, it was reported that quinoa seeds have high protein content (16%–23%) (Shams, 2011). These properties may have caused the leaves and panicles to have higher crude protein contents than the stem. Again, in late sowing, due to the increasing air temperatures, the plants grew thinner and the stem thickness decreased, and they had lower fiber content due to the decreasing stem thickness (Buxton and Redfearn, 1997; Fales and Fritz, 2007). Since this would decrease the stem/leaf ratio, the amount of structural substances, such as cellulose and lignin, in the plant structure would consequently be reduced, and the ratio of nonstructural carbohydrates, such as protein, would be increased (Özyiğit and Bilgen, 2006). In the studies conducted on forage plant species, it was also reported that the leaves had higher protein content than the stems (Fales and Fritz, 2007; Gülümser and Acar, 2012; Keleş, 2014).

In terms of the CPY, the highest was measured in the leaves of plants sown on SD_2, at 1144 kg ha^{-1}, while the lowest (329 kg ha^{-1}) was obtained in the stems of plants sown on SD_4 (Figure 2b). This may have been due to the fact that the leaves of plants sown on SD_2 had higher DMYs than the panicles (Figure 1b), and again the leaves had higher crude protein contents than the stem (Figure 2a). This may also have been caused by the fact that the stems had very low crude protein contents when compared to the other plant parts of those sown on SD_4, because the CPY is a value obtained by multiplying the crude protein ratio and DMY. In fact, it was reported that CPYs were decreased significantly in parallel with low DMYs in late sowings (Temel and Tan, 2002). While the CPY increased by 0.44% in the leaves of plants sown on SD_2, it decreased by 21.25% and 10.38% in the panicles and stems, respectively, and this may have resulted in the significance of the binary interaction.

For all 3 parameters, the sowing time × plant part interaction showed a significant difference at 1%. Thus, the highest NDF (64.97%–64.05%) and ADF (45.63%–44.90%) contents were obtained from the stems of plants sown on SD_1 and SD_2, while the highest ADL content was obtained from the stems of plants sown on SD_2 (20.53%). The lowest ADF content (8.95%–9.82%) was obtained from the leaves at all of the sowing periods, while the lowest NDF (21.20%) and ADL (3.57%) contents were determined inthe leaves of plants sown on SD_4 (Figures 3a–3c). This variation was thought to be the result of different anatomical and physiological structures of the leaves, stems, and panicles. In addition, it may also have been due to the fact that the plants showed weaker stem development due to the shortening of the vegetation period in the late sowings when compared to the early sowings, and therefore had a lower stem/leaf ratio (Table 3). In general, each tissue that constitutes a plant

[3] Jung HG (2012). Forage Digestibility: The Intersection of Cell Wall Lignification and Plant Tissue Anatomy [online]. Website http://dairy.ifas.ufl.edu/RNS/2012/12JungRNS2012.pdf [accessed 20 December 2019].

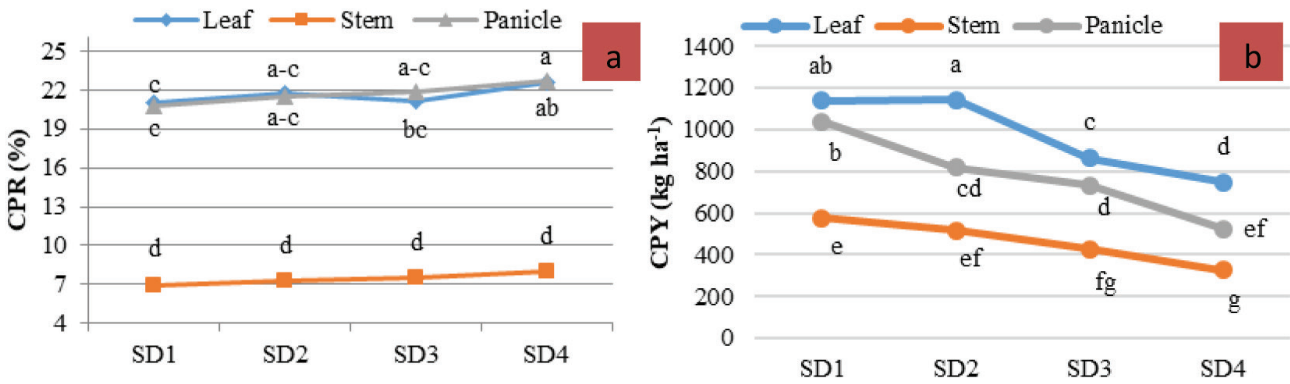

Figure 2. Effects of the sowing date × plant part interaction on the crude protein ratio (CPR) and crude protein yield (CPY). Plots represented by different letters were significant at P ≤ 0.01.

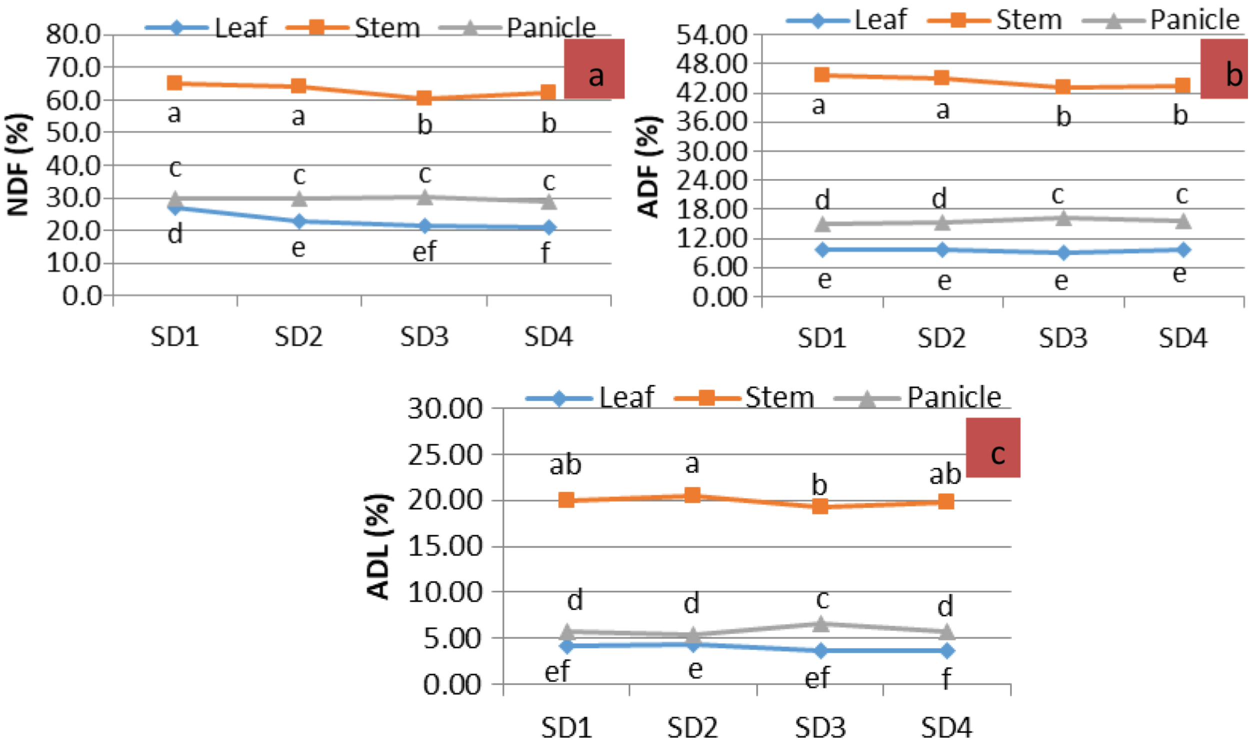

Figure 3. Effects of the sowing date × plant part interaction on the NDF, ADF, and ADL contents. Plots represented by different letters were significant at P ≤ 0.01.

part (cover, base, and transmission tissues) contains the cell types specialized for different functions (Taiz and Zeiger, 2002). For example, the cells in the stems are thicker-walled than the cells in leaves and panicles. Therefore, stems have a higher proportion of thick cell walls in comparison to those in the leaves and panicles (sclerenchyma and vascular tissues) (Grabber et al., 1991). This causes the structural carbohydrates, such as cellulose, hemicellulose, and lignin, that form the cell wall components (Moore and Jung, 2001) to be found in the stems athigher amounts (Collins and Fritz, 2003; Önal Aşcı and Acar, 2018). In addition, the leaves have mesophyll, phloem, and photosynthetic tissue with more thin cell walls than the stem[4]. Therefore, the NDF, ADF, and ADL contents were lower in these tissues,which showed less ligninization (Buxton and Redfearn, 1997). Hence, it was reported in studies conducted in legume and grass forage species that the stem had higher ADF,

[4] Jung HG (2012). Forage Digestibility: The Intersection of Cell Wall Lignification and Plant Tissue Anatomy [online]. Website http://dairy.ifas.ufl.edu/RNS/2012/12JungRNS2012.pdf [accessed 20 December 2019].

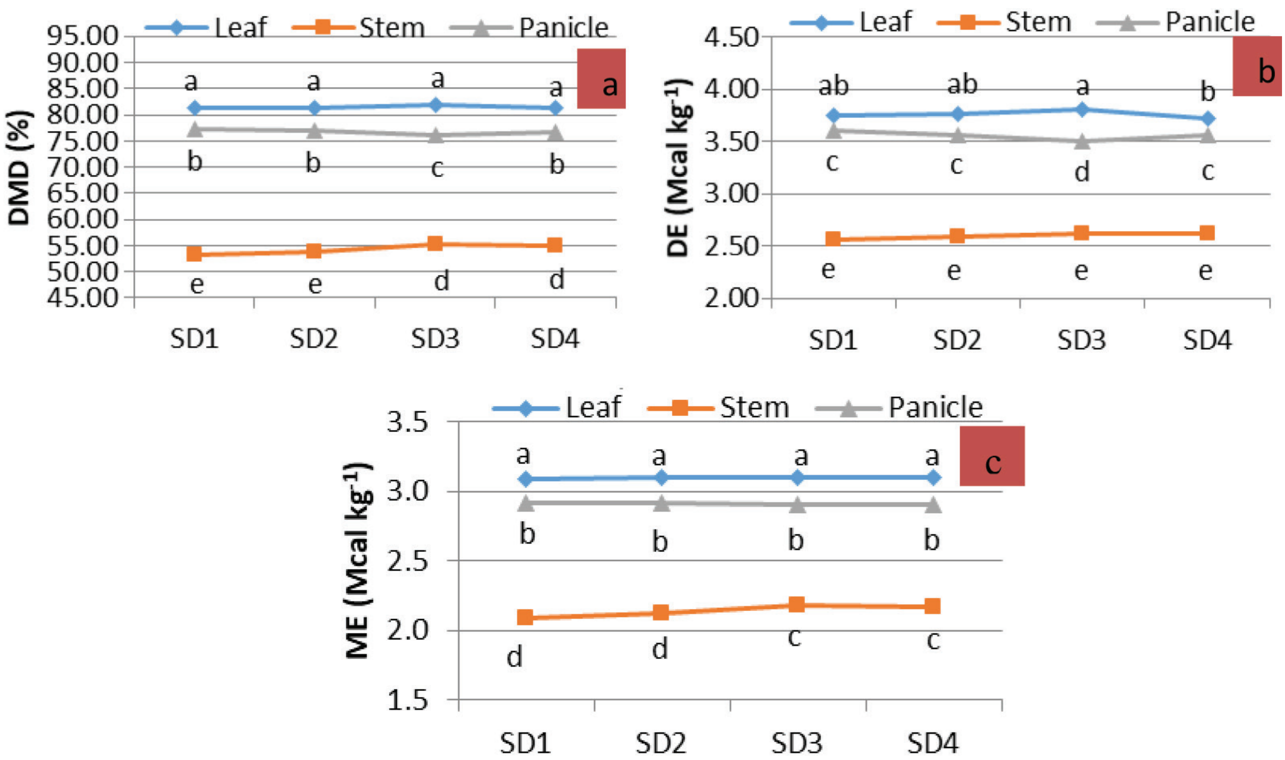

Figure 4. Effects of sowing date × plant part interaction on the DMD, DE, and ME contents. Plots represented by different letters were significant at P ≤ 0.01.

NDF, and ADL contents than the leaves (Fales and Fritz, 2007; Gülümser and Acar, 2012; Keleş, 2014).

The effect of the sowing time × plant part interaction on the DMD, DE and ME contents of quinoa showed statistically significant differences ($P \leq 0.01$). The highest DMD (81.25%–81.93%) and ME (3.08–3.10 Mcal kg^{-1}) contents were found in the leaves in all 4 sowing periods, and the lowest values were obtained from the stems of plants sown on SD_3 and SD_4 (Figures 4a and 4b). The highest DE content was determined in the leaves of plants sown on SD_3 (3.80 Mcal kg^{-1}), while the lowest amount was found in the stems (2.57–2.62 Mcal kg^{-1}) in all 4 sowing periods (Figure 4c). These differences may have been due to the fact that the plant parts had different ADF contents as a result ofthe sowing times (Figure 3b). Because the DMD is calculated from the ADF contents, the DE content from the DMD and ME contents from the SE, when the ADF contents increase, the DMD of the feed decreases, and the DE and ME contents decrease in parallel, and vice versa[5]. In general, the digestibility and energy contents of intracellular substances (protein, fat, and soluble carbohydrates) are higher than those of cell wall substances (cellulose, hemicellulose, lignin, and pectin) (Collins and Fritz, 2003). Moreover, the amount of cell wall substances is higher in the stems than in the leaf, and intracellular substances are found more in the leaves than in the stems (Buxton and Redfearn, 1997). Therefore, the stems can be digested less and the leaves can be digested more. Hence, the mean DMD, DE, and ME contents of the leaves and panicles were higher than those of the stems by 50%–41%, 45%–37%, and 45%–36%, respectively, in this study. It was also found in studies conducted on different species used as feed sources that the leaves had higher DMD, DE, and ME contents than the stems (Keleş, 2014; Dökülgen and Temel, 2015; Dökülgen and Temel, 2019).

The sowing time × plant part interaction was significant for the RFV. The highest RFV was determined in the leaves (356.6–353.5) of plants sown on SD_3 and SD_4, and the lowest value was found in the stems (76.4–84.8) of plants sown at all 4 sowing periods (Figure 5). When compared to plants sown SD_1, the RFVs of the stems and panicles remained constant, while the RFVs of the leaves increased by 18.49%, and this may have been the reason for the significance of the sowing time × plant part interaction. This may have been due to the higher NDF content of the leaves of the plants sown on $SD_1$when compared to those sown onSD_2–SD_4 (Figure 3a), because the RFV is measured by calculating the NDF and ADF contents of the feed. If

[5] Kutlu HR (2008). Feed Evaluation and Analysis Methods (lecture notes) [online]. Website http://www.zootekni.org.tr/upload/File/sunular/tm.pdf [accessed 20 June 2017].

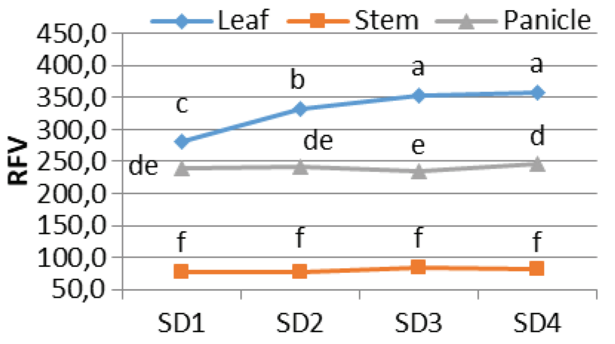

Figure 5. Effects of the sowing date × plant part interaction on the relative feed value (RFV). Plots represented by different letters were significant at P ≤ 0.01.

the RFV is below 75, the feed is considered as 5th quality, while a RFV score between 75 and 86 denotes 4th quality feed, 87 and 102 denotes 3rd quality, 103 and 124 denotes 2nd quality, 125 and 150 denotes 1st quality, and a RFV score above 150 is considered the best quality (Rohweder et al., 1978). Therefore, low NDF and ADF contents are desirable in order to have higher RFVs. According to these criteria, although the NDF and ADF contents of the quinoa stems were high, their RFVs were of the 4th quality, while those of the panicles and leaves were of the best quality. It was also reported that leaves have higher RFVs when compared to other plant parts in different species used for animal nutrition (Dökülgen and Temel, 2015; Dökülgen and Temel, 2019)

As a result, in this study, wherein the effects of different sowing times and plant parts on the hay yield and quality of quinoa were tested together, the panicles and, particularly, the leaves had at least 3 times higher CPR, DMD, DE, ME, and RFV than that of the stems of plants sown at all 4 periods, while they had at least 3 times lower NDF, ADF, and ADL contents. These results showed that the leaves and panicles contributed more to the nutritional content of quinoa hay than the stems. In terms of yield properties, it was observed that there were significant decreases in plant height, stem thickness, number of branches, panicle ratio, FHY, and DMY of plant parts (leaf, stem, and panicle) as the sowing time was delayed. Moreover, the stems, leaves, and panicles contributed more, respectively, to the amount of the hay obtained at all 4 sowing periods. According to these data, it was concluded that sowing should be performed without delay in quinoa cultivation and it would be appropriate to use quinoa varieties with high leaf and panicle ratios for the purpose of roughage production.

References

Abtahi Adolf VI, Jacobsen SE, Shabala S (2013). Salt tolerance mechanisms in quinoa (*Chenopodium quinoa* Willd.). Environmental and Experimental Botany 92: 43-54.

Association of Official Analytical Chemists (AOAC) (1997). Official Methods of Analysis. 16th ed. 3rd revision. Arlington, VA, USA: AOAC, p. 125.

Awadalla A, Morsy S (2017). Influence of planting dates and nitrogen fertilization on the performance of quinoa genotypes under Toshka conditions. Egyptian Journal of Agronomy 39: 27-40.

Bertero HD, KingandRW, Hall AJ (2000). Photoperiod and temperature effects on the rate of leaf appearance in quinoa (*Chenopodium quinoa*). Australian Journal of Plant Physiology 27: 349-356.

Bhargava A, Shukla S, Ohri D (2006). *Chenopodium quinoa*. An Indian perspective. Industrial Crops and Products 23: 73-87.

Bhargava A, Shukla S, Ohri D (2007). Effect of sowing dates and row spacings on yield and quality components of quinoa (*Chenopodium quinoa* Willd.) leaves. Indian Journal of Agricultural Science 77: 748-751.

Buxton DR (1996). Quality related characteristics of forages as influenced by plant environment and agronomic factors. Animal Feed Science and Technology 40: 109-119.

Buxton DR, Redfearn DD (1997). Plant limitations to fiber digestion and utilization. The Journal of Nutrition 127: 814-818.

Casini P (2019). Seed yield of two new quinoa (*Chenopodium quinoa* Willd.) breeding lines as affected by sowing date in Central Italy. Acta Agriculturae Slovenica 113: 51-62.

Collins M, Fritz JO (2003). Forage Quality. In: Barnes RF, Nelson CJ, Collins M, Moore KJ (editors). Forages, Vol. I. 6th ed. Oxford, UK: Blackwell Publishing Company, pp. 363-390.

Cusack DF (1984). Quinoa: grain of the incas. The Ecologist 14: 21-30.

Darwinkel A, Stølen O (1997). Understanding the quinoa crop: guidelines for growing in temperate regions of N.W. Europe. Brussels, Belgium: European Commission.

Dökülgen H, Temel S (2015). Seasonal nutrient content changes of leaf and leaf + shoots in deciduous Christ's thorn (*Paliru sspina-christi* Mill.). Iğdır University Journal of the Institute of Science and Technology 5: 57-65 (in Turkish with an abstract in English).

Dökülgen H, Temel S (2019). Determination of nutritional value of Terebinth and Styrax Tree according to the grazed plant parts and seasons. Harran Journal of Agricultural and Food Science 23: 178-188 (in Turkish with an abstract in English).

Fales SL, Fritz JO (2007). Factors Affecting Forage Quality. In: Barnes RF, Nelson CJ, Moore KJ, Collins M (editors). Forages, Vol. II. 6th ed. Oxford, UK: Blackwell Publishing Company, pp. 569-580.

Fonnesbeck PV, Clark DH, Garret WN, Speth CF (1984). Predicting energy utilization from alfalfa hay from the Western Region. Proceedings of American Animal Science 35: 305-308.

Fuentes F, Bhargava A (2011). Morphological analysis of quinoa germplasm grown under lowland desert conditions. Journal of Agronomy and Crop Science 197: 124-134.

Fuentes FF, Bazile D, Bhargava A, Martinez EA (2012). Implications of farmers' seed exchanges for on-farm conservation of quinoa, as revealed by its genetic diversity in Chile. Journal of Agricultural Sciences 15: 702-716.

Galwey NW (1989). Exploited plants - quinoa. Biologist 36: 267-274.

Geren H (2015). Effect of different nitrogen levels on the grain yield and some yield components of quinoa (*Chenopodium quinoa*Willd.) under Mediterranean climatic conditions. Turkish Journal of Field Crops 20: 59-64.

Geren H, Kavut YT, Topcu GD, Ekren S, Istipliler D (2014). Effects of different sowing dates on the grain yield and some yield components of quinoa (*Chenopodium quinoa* Willd.) grown under Mediterranean climatic conditions Journal of Ege University Faculty of Agriculture 51: 297-305.

Grabber J, Jung G, Hill R (1991). Chemical composition of parenchyma and sclerenchyma cell walls isolated from orchardgrass and switchgrass. Crop Science 31: 1058-1065.

Gülümser E, Acar Z (2012). Morphologıcal and chemical characters of *Bituminaria bituminosa* (L) C.H. (Stirtion) grown naturally in the middle black sea region. Turkish Journal of Field Crops 17: 101-104.

Hirich A, Choukr-Allah R, Jacobsen SE (2014). Quinoa in Morocco - effect of sowing dates on development and yield. Journal of Agronomy and Crop Science 200: 371-377.

Kacar B (2012). Soil Analysis. Ankara, Turkey: Nobel Publication Distribution.

Katsunori I, Hikaru S, Daisuke O, Yudai M, Hiroki H et al. (2016). Effects of sowing time on the seed yield of quinoa (*Chenopodium quinoa* Willd.) in south Kanto, Japan. Journal of Agricultural Sciences 7: 146-153.

Keleş G (2014). Nutritive value of morphological components in triticale forage harvested at different maturity stages. Journal of Animal Product 55: 1-6.

Khalil JK, Sawaya WN, Hyder SZ (1986). Nutrient composition of Atriplex leaves grown in Saudi Arabia. Journal of Range Management 39: 104-107.

Kır AE, Temel S (2016). Determination of seed yield and some agronomical characteristics of different quinoa (*Chenopodium quinoa* Willd.) variety and populations under dry conditions of Iğdır Plain. Iğdır Univesity Journal of the Institute of Science and Technology 4: 145-154.

Kır AE, Temel S (2017). Determination of seed yield and some agronomical characteristics of different quinoa (*Chenopodium quinoa* Willd.) genotypes under irrigated conditions. Iğdır Univesity Journal of the Institute of Science and Technology 7: 353-361.

MGM (2019). Iğdır Provincial Directorate of Meteorology. Iğdır, Turkey.

Moore KJ, Jung HG (2001). Lignin and fiber digestion. Journal of Range Management 54: 420-430.

Önal Aşcı O, Acar Z (2018). Quality of Roughage. Ankara, Turkey: Positive Printing and Packaging Industry Trade Company.

Özyiğit Y, Bilgen M (2006). Effect of different cutting stages on some quality factors in various legume forage crops. Mediterranean Agricultural Sciences 19: 29-34.

Peterson AJ, Murphy KM (2015). Quinoa Cultivation for Temperate North America: Considerations and Areas for Investigation. In: Murphy K, Matanguihan J (editors). Quinoa: Improvement and Sustainable Production. 1st ed. Malden, MA, USA: Wiley-Blackwell Publishing, pp.173-192.

Ramesh K (2016). Evaluation of quinoa (*Chenopodium quinoa* Willd.) at different dates of sowing and varied crop geometry in semi-arid regions of Telangana. Master of Science in Agriculture, Professor Jayashankar Telangana State Agricultural University, Telangana, India.

Rauf S, Khan AA, Desilva T, Naveed A (2010). Consequences of plant breeding on genetic diversity. International Journal of Plant Breeding and Genetics 4: 1-21.

Repo-Carrasco R, Espinoza C, Jacobsen S (2011). Nutritional value and use of the Andean crops quinoa (*Chenopodium quinoa*) and Kaniwa (*Chenopodium pallidicaule*). Food Reviews International 19: 179-189.

Rohweder DA, Barnes RF, Jorgensen N (1978). Proposed hay grading standards based on laboratory analyses for evaluating quality. Journal of Animal Science 47: 747-759.

Ruiz KB, Biondi S, Oses R, Acun˜a-Rodrı´guez IS, Antognoni F et al. (2014). Quinoa biodiversity and sustainability for food security under climate change. A review. Agronomy for Sustainable Development 34: 349-359.

Sajjad A, Munir H, Ehsanullah Anjum SA, Tanveer M, Rehman A (2014). Growth and development of quinoa (*Chenopodium quinoa* Willd.) at different sowing dates. Journal of Agricultural Research 52: 535-546.

Shams A (2011). Combat degradation in rain fed areas by introducing new drought tolerant crops in Egypt. International Journal of Water Resources and Arid Environments 1: 318-325.

Sheaffer CC, Peterson MA, Mccalin M, Volene JJ, Cherney JH et al. (1995). Acide detergent fiber, neutral detergent fiber concentration and relative feed value. In: North American Alfalfa Improvement Conference; Minneapolis, MN, USA.

Shoman HA (2018). Effect of sowing dates and nitrogen on productivity of quinoa (*Chenopodium quinoa* Willd.) at desert areas. Journal of Plant Production Mansoura University 9: 327-332.

Stikic R, Glamoclija D, Demin M, Vucelic-Radovic B, Javanovic Z et al. (2012). Agronomical and nutritional evaluation of quinoa seeds (*Chenopodium quinoa* Willd.) as an ingredient in bred formulations. Journal of Cereal Science 55: 132-138.

Taiz L, Zeiger E (2002). Plant Physiology. Sunderland, MA, USA: Sinauer Associates, Inc.

Tan M, Temel S (2017a). Studies on the adaptation of quinoa (*Chenopodium quinoa* Willd.) to Eastern Anatolia Region of Turkey. AGROFOR International Journal 2: 33-39.

Tan M, Temel S (2017b). Determination of dry matter yield and some properties of different quinoa genotypes grown in Erzurum and Iğdır conditions. Iğdır Univesity Journal of the Institute of Science and Technology 7: 257-263.

Tan M, Temel S (2012). Alternative Feed Crops. Atatürk University Agricultural Faculty Course Publications No: 246. Erzurum, Turkey: Atatürk University Agricultural Faculty.

Tan M, Temel S (2018). Performance of some quinoa (*Chenopodium quinoa* Willd.) genotypes grown in different climate conditions. Turkish Journal of Field Crops 23: 180-186.

Temel S, Tan M (2002). A research on determination of seeding and cutting time in common vetch (*Vicia sativa* L.) under Erzurum conditions. Atatürk University Journal of the Agricultural Faculty 33: 363-368.

Ujiie K, Sasagawa R, Yamashita A, Isobe K, Ishii R (2007). Agronomic studies onquinoa (*Chenopodium quinoa* Willd.) cultivation in Japan. Japanese Journal of Crop Science 76: 59-64 (in Japanese with an abstract in English).

Van Soest PJ, Robertson JB, Lewis BA (1991). Methods for dietary fiber, neutral detergent fiber and nonstarch polysaccharides in relation to animal nutrition. Journal of Dairy Science 74 (10): 3583-3597.

Yolcu S (2018). Determination of sowing and harvest times on hay yield and quality of quinoa (*Chenopodium quinoa* Willd.) plant grown under irrigated conditions in Iğdır. Graduate Thesis, Iğdır University, Iğdır, Turkey.