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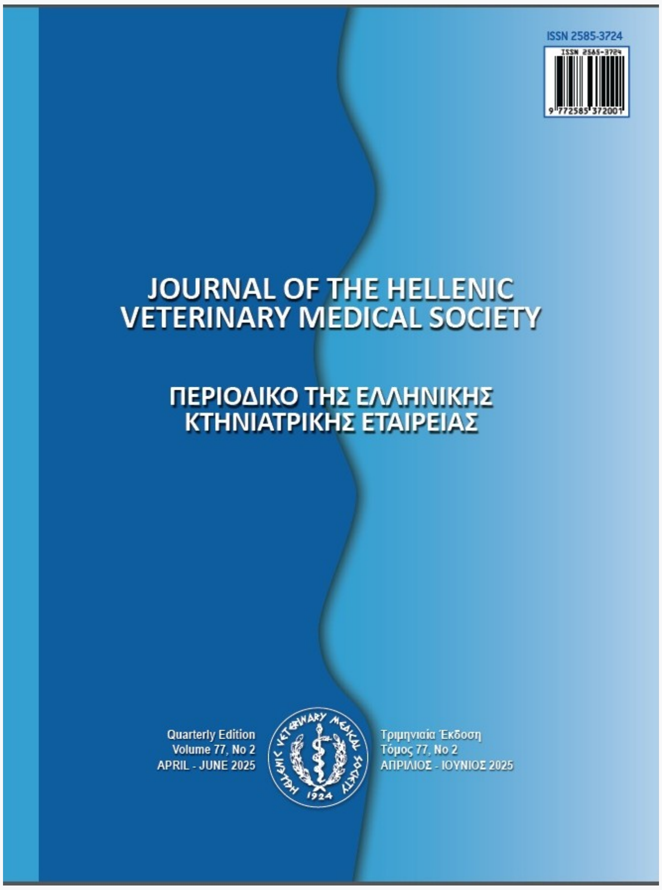

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Physical and Chemical Properties of Ensiled Safflower (*Carthamus tinctorius* L.) Cultivars at Three Development Stages

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ABSTRACT: This study aimed to assess the physical and chemical properties of silages made from six safflower cultivars, harvested at three distinct developments stages in Uşak, Türkiye in 2020. The safflower cultivars were ensiled without additives during the budding, blooming, and seed-filling stages, with three replications. The study evaluated the physical characteristics and DLG scores of the silages, alongside measurements of dry matter content (DM), pH, Flieg score (FS), crude protein (CP), crude fat (CF), crude ash (CA), neutral detergent fiber (NDF), acid detergent fiber (ADF), digestible dry matter (DDM), dry matter intake (DMI), and relative feed value (RFV). The results revealed no statistically significant difference (p>0.05) in the physical properties, DLG score, and pH values among the safflower silages. However, significant differences (p<0.05) were observed in the DM (33.96% to 40.20%), CF (1.28% to 2.3%), CA (8.44% to 9.17%), NDF (43.40% to 47.44%), ADF (32.32% to 36.18%), DDM (60.72% to 63.75%), DMI (2.53% to 2.77%), and RFV (153.74 to 176.79) values across the different safflower cultivars. Advancing development resulted in increased DM content (24.62% to 48.00%), FS (80.01 to 131.50), CA content (1.12% to 3.03%), NDF content (43.04% to 47.62%), and ADF content (32.86% to 35.12%). Conversely, it led to decreases in CP content (14.66% to 7.65%), CA content (11.14% to 6.56%), DDM content (63.30% to 61.55%), DMI (2.80% to 2.53%), and RFV (177.10 to 155.49). In conclusion, all safflower cultivars demonstrated commendable relative forage values (RFV), with the Olas and Linas cultivars exhibiting superior performance compared to the others. From a harvest management standpoint, ensiling at the budding stage is identified as the most effective practice.

Keyword: Cultivar; development; quality; safflower; silage.

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INTRODUCTION

Rising labor costs in Türkiye, as in numerous other nations, are gradually leading to a decline in pasture-based animal husbandry. Traditional livestock operations centered on grazing are being supplanted by intensive farming enterprises that yield higher quantities of meat and milk. Since the 2000s, the genetic potential of cattle raised in Türkiye has significantly improved. However, to maximize meat and milk yields from these animals, both environmental conditions and feed resources require enhancement. Alongside concentrated feeds, incorporating high-quality forages like silage into animal nutrition is crucial. Nevertheless, agricultural production in arid regions faces constraints due to drought and irregular rainfall distribution throughout the year. The irregularities in autumn rainfall, particularly prevalent in central and southern regions of Türkiye, result in germination losses and cold damage due to delayed germination. Additionally, spring droughts lead to significant yield losses across various crops. These challenges pose difficulties for livestock enterprises in dry farming areas to acquire high-quality silage. Consequently, farmers in arid regions are actively seeking forage plants that exhibit resilience to both cold temperatures and drought conditions while still being capable of producing high-quality silage.

Safflower, a valuable annual oil plant belonging to the *Compositae* family, comes in both spiny and spineless varieties. With roots capable of reaching an average depth of 2.5-3.0 meters, safflower exhibits remarkable adaptability to dry areas (Mündel *et al*., 2004). Safflower, known for its ability to thrive in barren and poor soils, offers higher yields compared to many other plants in such conditions. Moreover, it demonstrates tolerance to salinity (Ghiyasi *et al*. 2023; Beyyavas *et al*. 2024). While safflower is primarily recognized as a valuable oil plant, research indicates that it performs exceptionally well in marginal agricultural areas due to its drought resistance (Kaplan *et al*., 2024). Studies have revealed that when harvested at appropriate development stages, safflower can be utilized as a high-quality forage crop (Mündel *et al*., 2004; Peiretti, 2017; Akgün and Söylemez, 2022). Landau *et al*. (2004) highlighted that safflower is a promising source for producing quality silage in the nutrition of dairy cattle. They reported that safflower hay harvested during the pre-flowering period contained 13.4% CP, while its silage contained 15.6% CP. Additionally, it was noted that safflower cultivated areas in Australia were utilized for grazing by cattle and sheep during early vegetative periods (Jackson and Berthelsen, 1986). Another study emphasized that safflower should be recognized as a high-quality forage crop suitable for arid and semi-arid regions with limited water resources. This study pointed out that the CP content of safflower ranged from 8.18% to 12.81%, while the NDF and ADF ratios varied between 44.80% to 59.8% and 30.9% to 43.9%, respectively (Bar-Tal *et al*., 2008). Safflower harvested at the budding stage has been successfully ensiled, as demonstrated by Weinberg *et al*. (2007). Moreover, studies have shown that safflower silage can effectively replace cereal silage in the diets of high-yielding dairy cows (Landau *et al*., 2004) and dairy sheep (Landau *et al*., 2005) without compromising their daily performance.

Safflower emerges as a valuable silage option for regions where crops like corn and sorghum struggle to grow due to drought conditions. Consequently, it serves as a crucial resource for fulfilling the silage requirements of animals in arid and semi-arid areas. The present study aims to assess various physical and quality attributes of safflower cultivars silages harvested and ensiled during three distinct developmental stages.

MATERIALS AND METHODS

The study was carried out at the Faculty of Agriculture, Uşak University (38°40'N, 29°19'E, elevation 980 m), in Türkiye, during 2020. Six safflower varieties cultivated in Türkiye (Balcı, Dinçer, Linas, Olas, Remzibey, and Yenice) were used as silage materials. Among these cultivars, Dinçer and Yenice are spineless varieties, while the others have spines. Concerning flower color, Balcı, Olas, and Remzibey exhibit yellow flowers, Dinçer and Linas have orange flowers, and Yenice has red flowers. Regarding fatty acids, Balcı, Dinçer, Linas, and Yenice varieties are classified as linoleic type (C18:2), while Olas is categorized as oleic type (C18:1), and Remzibey is considered semi-oleic type.

Harvesting and ensiling

In the study, safflower cultivars were harvested at three developmental stages: budding on June 25th, blooming on July 9th, and seed filling on July 29th in 2020. Following each harvest, the safflower plants were chopped in the laboratory using a grinding machine to achieve a particle size of less than 1 cm in length. The chopped materials from each stage of harvest were then packed and compacted into 1-1.5-liter glass jars without any additives. These jars were sealed to minimize exposure to air and allowed to ferment for 60 days. After the fermentation period, the silo jars were opened for analysis (Siesfers and Bolsen, 1997).

The physical and chemical analysis

The physical characteristics of the silages, such as color, odor, and structure, were assessed by four experienced silage specialists using the German Agriculture Organization silage rating scale (DLG, 1987). In this scale, these scores are used 14 (no butyric acid smell, aromatic smell), 10 (little butyric acid smell, strong smell), 4 (moderate butyric acid smell, mould smell), 2 (strong butyric acid smell, NH_3 smell), 0 (strong mould smell) for odor, 4 (no distortion), 2 (a little distortion), 1 (distortion, mould), 0 (decaying) for outer view, 2 (preserves its color the way it was ensiled), 1 (a little change in the color), 0 (a totally different color) for color. Samples from each jar were dried in a 70°C oven until they reached a constant weight to determine the DM content, following the method described by Martin *et al*. (1990). For pH determination, 25 ml of distilled water was added to 10 g of silage, and the pH was measured using a digital pH meter, as outlined in the DLG (1987) guidelines. The flieg scores were calculated using the formula proposed by Denek *et al*. (2004);

Fleig Score = 220+(2 *x DM%* – 15) – 40 *x pH*

The CP contents of the silage were determined by multiplying the Kjeldahl nitrogen concentration by 6.25, as described by Kacar and İnal (2008). Crude fat content in the silages was assessed using a Nuclear Magnetic Resonance (NMR Brüker mq_{one}) device, following the method outlined in ISO 10565. The samples were dried by kept in an oven set at 70 °C for 48 hours and weighed 2 g, and the average crude fat content was calculated in 6 replications for each silage jar (Erbaş and Şenateş, 2020). The crude ash content of silages was found using the procedure defined by Akyıldız (1984). NDF and ADF contents were performed according to the protocols provided by ANKOM Technology (Anonymous, 2019).

DDM, DMI and RFV were calculated using the equations:

DDM (%) = 88.9 – (0.779 *x ADF*%)

DD1 (%) = 120/(*NDF*%)

RFV = (*DDM*% *x DM1*%)/1.29

These calculations were performed based on the methods described by Holland *et al*. (1990).

Statistical analysis

Data on the chemical composition of the safflower silages were analyzed by analysis of variance using JMP version 11.0.0 software (SAS Institute Inc. 2013). The statistical analysis was applied to data following the randomized complete block design with three replications. Means were compared using the least significant difference (LSD) test when the overall F-tests were significant (P<0.05).

RESULTS

The variance analysis results and mean squares determined in the research are presented in Table 1. Accordingly, safflower cultivars were effective on all properties of silages except CP, pH, and FS. Harvest times had a significant effect on all silage parameters except pH. While the cultivar x harvest times interaction had an effect on DM, CP, CO, and FS among the traits investigated, it had no statistically significant effect on the other parameters.

Table 1. Analysis of variance results and mean squares for determined properties in silages of different safflower cultivars harvested at various stages.

Variation Sources	DF	Mean Square										
		DM	pH	FS	CP	CF	CA	NDF	ADF	DDM	DMI	RFV
Block	2	3.29	0.01	48.03	0.52	0.01	0.01	2.45	0.44	0.27	0.010	41.29
Cultivars (C)	5	71.13**	0.09	54.47	0.48	3.71**	0.73*	24.05**	23.52**	14.27**	0.082**	732.19**
Harvest Times (HT)	2	2479.9**	0.08	12241**	221.64**	8.52**	95.49**	94.78**	23.06**	13.99**	0.329**	2106.36**
C x HT Int.	10	1.64**	0.05	122.93*	1.42*	4.03**	0.29	3.51	1.54	0.94	0.011	5.87
Error	34	1.14	0.04	57.25	0.53	0.02	0.23	2.06	3.24	1.96	0.007	68.32
CV (%)		2.65	4.46	11.79	8.54	7.31	5.51	3.16	5.30	2.24	3.2	4.98

DF: Degrees of freedom, DM: Dry matter content, FS: Flieg score, CP: Crude protein content, CO: Crude fat content, CA: Crude ash content, NDF: Neutral detergent fiber, ADF: Acid detergent fiber, DDM: Digestible dry matter, DMI: Dry matter intake, RFV: Relative feed value, CV: Coefficient of variation, *: Statistical significance at the level of P<0.05, **: Statistical significance at the level of P<0.01.

The physical characteristics and DLG scores

The physical characteristics of safflower silages, including odor, structure, color, and DLG scores, are depicted in Figure 1 (a, b, c, d respectively). It appears that the statistical analysis conducted did not find any significant differences in the odor, structure, color, and DLG scores of silages based on cultivars, harvest times, or the interaction between cultivars and harvest times. This suggests that these factors did not have a noticeable impact on these aspects of the physical quality of silages in the study (P>0.05). The observed values for odor, structure, and color ranged from 11.33 to 13.67, 3.78 to 4.00, and 1.78 to 2.00, respectively. The DLG scores of safflower silages fell within the range of 17.02 to 19.67.

DM content and pH

While cultivars and harvest time applications have been found to significantly affect the DM (Dry Matter) contents of silages at the P<0.01 level, the DM contents vary between 33.96% and 40.20% across varieties (Table 2). The highest DM content was observed in the Olas and Balcı cultivars, while the lowest was found in the Dinçer and Yenice cultivars. Furthermore, the DM content of the Remzibey cultivar at the third harvest time was relatively lower compared to that of other cultivars, emphasizing the significance of the cultivar x harvest time interaction (Figure 2a). Delayed harvest times resulted in an increase in the DM content of the silages, ranging from 24.62% to 48.00% (Table 2). This increase was found to be statistically significant at the P<0.01 level (Table 1). In the study, the highest DM content was observed during the seed filling period, while the lowest DM content was observed in the silages harvested and ensiled during the budding period. In the study, no statistically significant effect of cultivars, harvest times, and cultivar x harvest time interaction was observed on the pH of silages (P>0.05). The pH values of the silages varied between 4.14 and 4.40 depending on the cultivars and between 4.24 and 4.36 depending on the harvest time (Table 2).

Flieg score

The flieg scores of the ensiled safflower cultivars did not show significant differences from each other. The Flieg scores ranged between 103.67 and 110.61 across the cultivars. However, harvest times had a

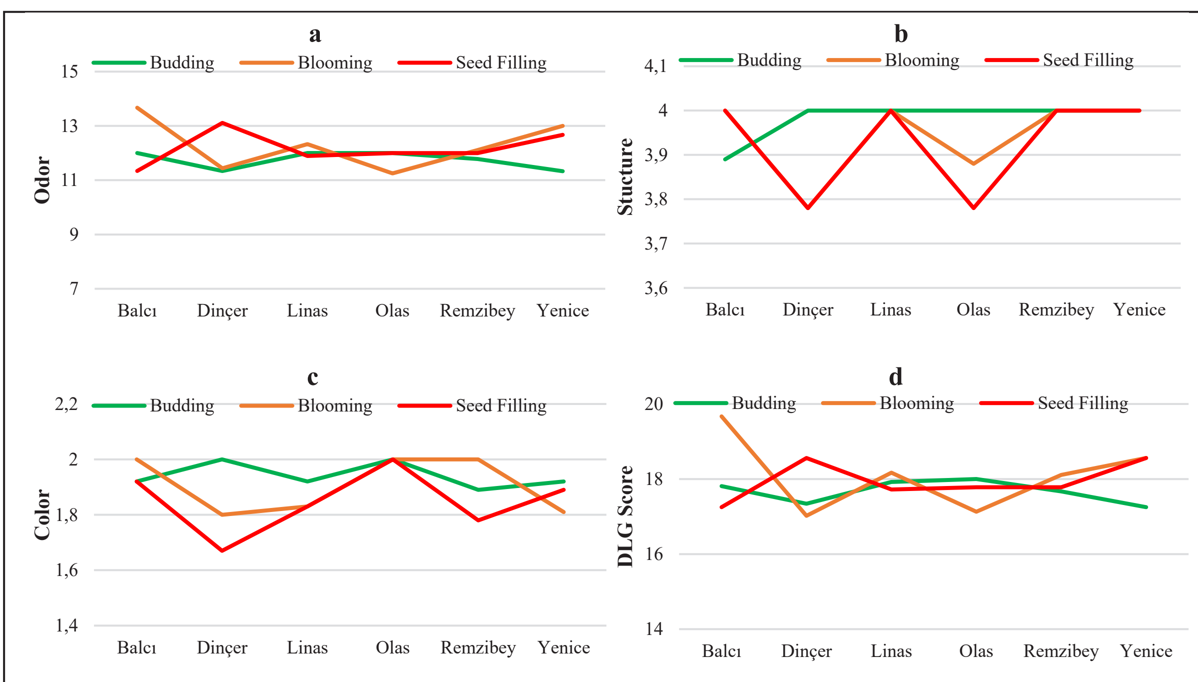

Figure 1. The physical properties of safflower cultivar silages harvested at different stages of development and ensiled include a, odor; b, structure; c, color, and d, DLG score. Harvest times are represented by colored lines: green for budding, orange for blooming, and red for seed filling. The cultivars are positioned along the horizontal axis for each physical parameter (a, b, c, d). Statistical analysis indicated that there were no statistically significant differences observed in terms of odor, structure, color, and DLG score (P>0.05).

Table 2. The effect of cultivars and harvest times on chemical characteristics of safflower silages

Cultivars	DM (%)	pH	FS	CP (%)	CF (%)	CA (%)
Balcı	39.69 ab	4.35	110.61	10.98	2.09 b	8.93 ab
Dinçer	33.96 d	4.14	107.55	10.71	1.29 de	8.55 bc
Linas	35.71 c	4.22	108.01	10.62	1.63 c	8.44 c
Olas	40.20 a	4.40	109.29	11.27	2.93 a	8.52 bc
Remzibey	39.00 b	4.32	109.71	11.18	1.42 d	8.60 bc
Yenice	34.31 d	4.25	103.67	11.41	1.28 e	9.17 a
$LSD_{0.05}$	1.02	ns	ns	ns	0.13	0.46
Harvest Times						
Budding	24.62 c	4.36	80.01 c	14.66 a	1.12 b	11.14 a
Blooming	38.81 b	4.24	112.91 b	10.78 b	1.18 b	8.40 b
Seed Filling	48.00 a	4.24	131.50 a	7.65 c	3.03 a	6.56 c
$LSD_{0.05}$	0.72	ns	5.13	0.49	0.09	0.33

DM, Dry matter; FS, Flieg score; CP, Crude protein; CF, Crude fat, CA, Crude ash; ns, not significant (P>0.05). The differences between the averages indicated by the same letters are not significantly different at the P<0.05 level.

significant effect on silage flieg scores (FS) at the P<0.01 level (Table 1). In the study, the advanced harvest period led to an increase in silage FS. The highest FS value, 131.50, was observed during the seed-filling period, whereas the lowest FS value, 80.01, was recorded during the budding stage (Table 2). Specifically, the Olas variety's higher DM content at the seed-filling stage resulted in a greater FS compared to other cultivars. Consequently, the cultivar x harvest time interaction was found to be significant at the P<0.05 level (Figure 2b).

CP content

The average crude protein (CP) contents of the safflower cultivars identified in the study are presented in Table 2. The CP contents of safflower silages ranged from 10.62% to 11.41%, varying by cultivar, with no statistically significant differences observed. Harvesting at an advanced stage resulted in a reduction in CP content, with statistically significant differences observed (P<0.01). Specifically, the highest CP content was determined as 14.66% during the budding period, whereas the lowest was 7.65% during the seed-filling period. Additionally, the CP contents of cultivars were differently affected by harvest times, resulting in statistically significant interactions (Figure 3a). The interaction between variety and harvest time resulted in CP contents ranging from 6.91% to 15.60%. Notably, the fluctuations in CP contents of cultivars, driven by varying harvest

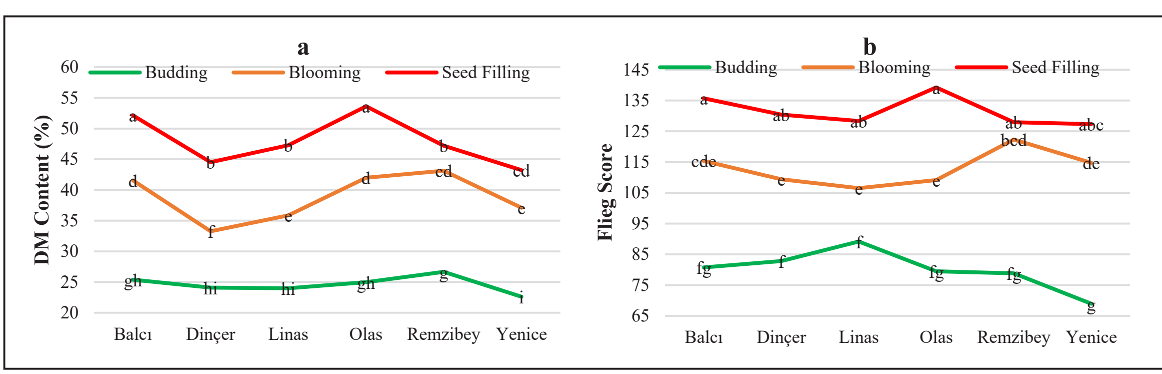

Figure 2. The effect of harvest time and cultivar interaction on the DM contents (a) (P<0.01) and Flieg scores (b) (P<0.05) of the safflower silages (LSD0.05 a: 1.77; b: 12.56). Harvest times are represented by colored lines: green for budding, orange for blooming, and red for seed filling. The safflower cultivars are positioned along the horizontal axis. Differences between the means represented by the same letter in both a and b are statistically insignificant at the P<0.05 level.

times, significantly contribute to this observed interaction.

CF and CA contents

The crude fat (CF) contents of the cultivars used in silage varied significantly between 1.29% and 2.93% ($P<0.01$). The Olas cultivar exhibited the highest CF content, whereas the Yenice and Dinçer cultivars had the lowest (Table 2). Harvest timing also exerted significant effects on the CF content of silages ($P<0.01$). The CF content during the seed-filling period (3.03%) surpassed that of the budding and flowering periods (1.12% and 1.18%, respectively). Furthermore, the CF content of 6.17% in the Olas safflower cultivar, recorded during the seed filling period and notably higher compared to other varieties, resulted in statistically significant differences in the cultivar x harvest time interaction ($P<0.01$). In the study, it was found that the CF contents of the silages varied between 0.58% and 6.17% based on these interactions (Figure 3b). In the study, significant differences were observed among the cultivars in terms of crude ash (CA) content at the $P<0.05$ level. The Yenice variety, characterized by a mid-late vegetation period and spineless characteristics, exhibited the highest CA content (9.17%), which was statistically equivalent to Balcı (8.93%). However, all other cultivars examined in the study showed similar CA contents, which were lower compared to Yenice and Balcı (Table 2). Additionally, considering the developmental stages, the CA content of silages decreased from 11.14% to 6.56% from the budding to seed-filling stage, a difference that was significant at the $P<0.01$ level.

NDF and ADF contents

An average of NDF and ADF contents identified in the research is shown in Table 3. While significant differences were observed between cultivars in terms of NDF contents, the values ranged from 43.40% to 47.44 %. The spineless Dinçer and Yenice cultivars exhibited the highest NDF contents, while the Olas and Linas varieties had the lowest. A similar trend was noted for ADF ratios, with Dinçer and Balcı cultivars displaying the highest ADF rates, while others clustered in the same statistical group with the lowest ADF contents. As expected, increasing plant maturity was associated with higher NDF and ADF contents. Depending on harvest time, NDF in silages ranged between 43.04% and 47.62%, while ADF varied from 32.86% to 35.12%. The highest values for both parameters were determined during the seed filling period, while the lowest values were observed in silages made during the budding period.

DDM, DMI, and RFV

Statistically significant differences at the $P<0.01$ level were observed in DDM contents among cultivars' silages (Table 1). The lowest DDM contents were recorded in the Dinçer and Balcı cultivars (60.72% and 61.25%, respectively), while other cultivars fell within the same statistical group (Table 3). Furthermore, delayed harvest resulted in reduced DDM content from 63.30% to 61.55% ($P<0.01$). Based on the study's findings, dry matter intake (DMI) values exhibited variations ranging from 2.53% to 2.75% across different safflower cultivars and between 2.80% and 2.53% across various harvest times. Olas emerged as the cultivar with the highest DMI value,

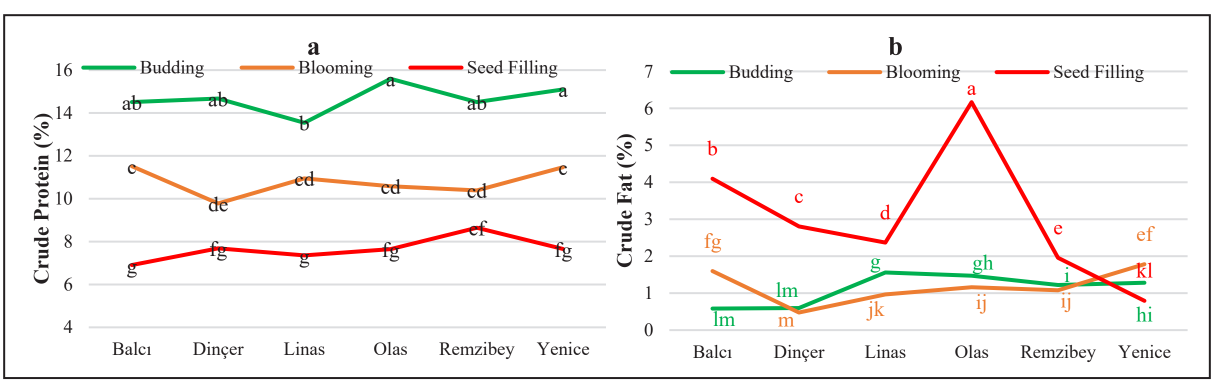

Figure 3. The effect of cultivar x harvest time interaction on the CP and CF contents of the safflower silages. The cultivar x harvest time interaction had a significant effect on both the CP ($P<0.05$) and CF contents ($P<0.01$) of the safflower silages (LSD0.05: CP: 1.20; CF: 0.22). In Figure a and b, harvest times are denoted by colored lines: green for budding, orange for blooming, and red for seed filling. The cultivars are arranged along the horizontal axis. The differences between the means represented by the same lowercase letter in the figure, for both CP and CF contents, are statistically insignificant.

Table 3. Analyzing the influence of safflower cultivars and harvest times on silage characteristics: NDF, ADF, DDM, DMI, and RFV profiles.

Cultivars	NDF (%)	ADF (%)	DDM (%)	DMI (%)	RFV
Balcı	45.67 bc	35.50 ab	61.25 bc	2.64 b	161.67 b
Dinçer	47.44 a	36.18 a	60.72 c	2.53 c	153.74 c
Linas	43.68 d	32.32 c	63.72 a	2.75 b	175.69 a
Olas	43.40 d	32.28 c	63.75 a	2.77 a	176.79 a
Remzibey	45.37 c	33.43 c	62.85 a	2.65 b	166.94 b
Yenice	46.87 ab	33.87 bc	62.52 ab	2.57 bc	160.87 bc
$LSD_{0.05}$	1.38	1.82	1.34	0.08	7.92
Harvest Times					
Budding	43.04 c	32.86 b	63.30 a	2.80 a	177.10 a
Blooming	45.55 b	33.81 b	62.56 a	2.64 b	165.26 b
Seed Filling	47.62 a	35.12 a	61.55 b	2.53 c	155.49 c
$LSD_{0.05}$	0.97	1.22	0.95	0.06	5.60

NDF, Neutral detergent fiber; ADF, Acid detergent fiber; DDM, Digestible dry matter; DMI, Dry matter intake, RFV, Relative feed value. The differences between the averages indicated by the same letters are not significantly different at the P<0.05 level.

whereas Dinçer had the lowest DMI value among the varieties assessed. Generally, delaying the harvest time led to decreased DMI values in the silages. The highest DMI was observed during the budding period, while the lowest DMI was recorded in silages harvested and ensiled during the seed filling period. The research findings indicate that the influence of safflower cultivars and harvest times on the relative feed values (RFV) of silages was statistically significant at the P<0.01 level (Table 1). RFV values ranged from 153.74 to 176.79 across the different cultivars (Table 3). Olas and Linas cultivars exhibited the highest RFV, whereas Dinçer and Yenice cultivars displayed the lowest RFV. Nevertheless, all cultivars assessed in the study demonstrated superior quality forage characteristics based on RFV classification. Delayed harvest for safflower ensiling resulted in statistically significant decreases in RFV. The RFV, initially measured at 177.10 during the budding period harvest, decreased to 155.49 as a consequence of the delayed harvest (Table 3).

DISCUSSION

According to the silage quality classification determined by DLG, all safflower silages included in the study were classified as good or very good quality silage (DLG, 1987). This finding is consistent with previous studies on corn, sorghum, and corn-legume mixtures, where DLG scores also fell within the good and very good quality silage groups (Çarpıcı, 2016; Topçu *et al*., 2021; Nusrathali *et al*., 2021). Taking this into consideration, it can be said that safflower is capable of producing silage of very good quality.

The disparity in DM content among cultivars may stem from their genetic structures, with spineless cultivars (such as Dinçer and Yenice) notably exhibiting the lowest DM content. Ochoa-Espinoza *et al*. (2022) argue that, during later stages of development, spineless safflower varieties yield higher-quality feed compared to their spiny counterparts. The observed difference in the interaction between cultivar and harvest time is thought to be due to variations in the maturation times of the cultivars. Baydar and Kara (2014) previously reported that the DM accumulation of late-maturing safflower genotypes tends to be slower compared to early-maturing cultivars. Regarding the variation in DM content across different harvest times, Peiretti *et al*. (2009) observed a progressive increase in DM content as the crop advanced through morphological stages, rising from 8.3% during the late vegetative stage to 15.7% during the early flowering stage. Similar trends were noted in safflower cultivated for hay and ensiling, with DM content escalating from 12.3% at the budding stage to 52.0% at the seed-filling stage (Corleto *et al*., 2005). Furthermore, previous studies consistently show that the DM content of safflower and other forage crops increases as their developmental stage progresses (Landau *et al*., 2005; Yıldız *et al*., 2010; Kavut and Geren, 2017; Çalışkan and Yüksel, 2022). In light of these findings, our study aligns with the conclusions drawn by other researchers.

Previous research has indicated that the pH values of safflower silages typically range between 3.90 and 5.47, depending on various factors, including wilting time (Weinberg *et al*., 2002; Landau *et al*., 2004). The findings of this study are consistent with these reported results. However, in contrast to the findings of this study, Corleto *et al*. (2008) reported pH values for safflower silages made at three different development stages ranging from 6.07 to 6.13. It's noteworthy that despite this variation in pH values, there was no statistical difference observed between the silages in their study. Notably, all silages in the study were classified into the high-quality silage group according to the scale reported by Denek *et al*. (2004). The FS is directly influenced by the DM and pH values of silages. Therefore, the advancement in maturity of the plant at harvest time resulted in increased DM and consequently higher FS values. It is worth noting that advancing maturity at harvest enhances FS due to the higher DM content (Yuksel, 2019). Additionally, there is a decrease in intensive fermentation and proteolysis as a result of the higher DM content in silage (Cazzato *et al*., 2011).

In this study, the CP contents of safflower silages varied between 10.62% and 11.41%, with no statistically significant differences found among the cultivars. However, Ochoa-Espinoza *et al*. (2022) reported CP contents ranging from 22.2% to 24.7% in their study, with no difference between spiny and spineless safflower cultivars. These values are notably higher than those observed in our study, which may be attributed to differences in harvest time. Notably, a sharp decrease in CP content during the flowering period for Dinçer and Olas cultivars, as well as during the seed-filling period for the Yenice cultivar, contributed to this interaction (Figure 3). This phenomenon can be explained by the decrease in leaf ratio and increase in stem ratio of plants during the generative period, leading to a proportional decrease in CP content due to the accumulation of carbohydrates and structural substances in the stems (Bakoğlu *et al*., 1999). Consequently, increasing maturity tends to reduce the CP content in plants. Cazzato *et al*. (2011) reported a decline in CP from 15.2% to 8.3% during the later stages of safflower development, which aligns with our results. Similarly, Peiretti (2009) observed a reduction in CP from 27.2% to 12.4% from the late vegetative period to the beginning of flowering in safflower silages, which is consistent with the trend we observed. Furthermore, Landau *et al*. (2005) determined a CP content of 15.6% in safflower silages when harvested at 28.9% DM content, which corresponds well with our findings. These studies collectively support the notion that safflower silage undergoes a reduction in CP content as it progresses through the later stages of development, reinforcing the findings of our study.

These discrepancies among cultivars regarding CF contents may stem from genetic characteristics such as flowering time, harvest index, and fatty acid composition. For instance, Baydar and Kara (2014) noted that the Yenice cultivar tended to have a mid-late flowering time, while the Dinçer and Remzibey varieties flowered earlier. Additionally, this variation may be attributed to Olas being an oleic-type safflower variety. Previous studies have indicated that high temperatures promote oleic acid synthesis while inhibiting the synthesis of linoleic and linolenic acids (Stryer, 1986; Röbbelen *et al*., 1989). Regarding the harvest times, Peiretti (2009) found the highest CF content in safflower during the late vegetative and full branching stages (2.9% and 2.6%, respectively). Stanford *et al*. (2001) observed an increase in CF from 1.6% to 13.1% between full flowering and mature safflower, which is consistent with our results. However, there are conflicting reports; for instance, a study suggested that the CF content of safflower remains stable as it matures (Cazzato *et al*., 2011).

The genetic structure of cultivars may be the primary factor contributing to the variations in CA content among them, while the timing of flowering could also influence CA levels. Furthermore, differences in leaf-to-stem ratios among cultivars might play a role in this variation. One of the main reasons for the decline in CA percentages in silage as the harvest time advances is the decrease in the proportion of leaves. It is known that ash is primarily concentrated in plant leaves, with minerals being transported from the roots to the leaves through water accumulation due to transpiration. This mineral accumulation in leaves results in an increase in CA content (Özyiğit and Bilgen, 2006). Several studies have reported similar findings, indicating that increased maturity leads to a reduction in CA content (Peiretti, 2009; Cazzato *et al*., 2011).

The observed differences in NDF and ADF ratios among the cultivars can be attributed to specific characteristics inherent to each variety, such as plant height, leaf-to-stem ratio, and stem thickness. Tall plants with robust stems tend to have higher total structural carbohydrate levels. Previous studies have highlighted a significant and positive correlation between plant height, stem ratio, NDF, and ADF content (Çaçan *et al*., 2018; Erol *et al*., 2022).

NDF and ADF contents determined in this study exceeded those reported by Stanford *et al*. (2001) and Landau *et al*. (2004) for full-bloom safflower herbage (42.9% NDF, 29.8% ADF) and late-budding safflower herbage (32.2% NDF, 23.3% ADF), respectively. However, our results were lower than those reported by Cazzato *et al*. (2011) and similar to those of Weinberg *et al*. (2007). Discrepancies may stem from varying environmental conditions and methodological factors considered across studies. Many researchers have noted that NDF and ADF contents decrease with delayed harvest (Stanford *et al*., 2001; Peiretti, 2009; Cazzato *et al*., 2011; Ochoa-Espinoza *et al*., 2022), which aligns with the findings of this study. Conversely, Weinberg *et al*. (2007) emphasized that there were no statistically significant differences between NDF and ADF contents of safflower silages harvested during the late budding period and the full blooming period.

DDM is calculated based on the content of ADF; an increase in ADF content results in a decrease in DDM. Therefore, fluctuations in DDM content observed in this study were inversely proportional to fluctuations in ADF content. A similar situation was stated in Ramazan *et al*. (2022) in sorghum-sudangrass silage. Consistent with our findings, Weinberg *et al*. (2007) also noted a negative impact of delayed harvest on DDM content, with values declining from 71.1% to 65.4%. Similarly, Landau *et al*. (2004) reported a DDM content of 62.5% for safflower herbage during the late budding period, aligning with our results.

The percentage of NDF content plays a crucial role in determining the dry matter intake (DMI) rate, which estimates the amount of forage an animal can consume as a percentage of its body weight (Boman, 2003). Forages with lower NDF ratios tend to have higher DMI ratios, whereas forages with lower digestibility occupy the digestive systems of animals for longer periods, consequently reducing DMI values (Shi *et al*. 2023; Stypinski *et al*. 2024). Since forages with higher DMI values are consumed more readily by animals, it can be inferred that the palatability of silages declines with advancing harvest time.

According to the American Feed and Pasture Council (AFGC) classification for legumes, grasses, and legume-grass mixture forages, the relative feed value (RFV) serves as a crucial indicator. If the RFV of a feed exceeds 151, it is deemed superior quality; falls between 125-151, it is considered high quality; between 103-124, it is categorized as good quality; between 87-102, it is considered medium quality; between 75-86, it is classified as poor quality; and anything lower than 75 is deemed very poor quality (Linn and Martin, 1989). Based on this classification, all silages examined in the study were classified as superior-quality feed owing to their RFV values. In contrast, a study on safflower herbage revealed RFV ranging between 92.3% to 130.3% (Jabbari *et al*., 2023), indicating comparatively lower values than those obtained in our study. The increase in herbage digestibility attributed to ensiling might explain this variation. Additionally, Selçuk *et al*. (2023) reported RFV values for safflower straw leftover from seed harvest, ranging from 116.79 to 142.67, also lower than the results of our study.

CONCLUSION

According to the results, all safflower cultivars exhibited successful ensiling based on fermentation characteristics such as DLG score, pH, and FS, with no significant differences observed. While the CP content did not vary significantly across cultivars, the Olas variety stood out for its higher CF content, while Balcı and Yenice had higher CA content. Additionally, the Olas and Linas cultivars demonstrated greater digestibility compared to other cultivars due to their lower NDF and ADF levels and higher RFV.

Throughout the harvest stages from budding to seed-filling, there were significant increases in DM, FS, CF, NDF, and ADF values, while CP, CA, DDM, DMI, and RFV decreased significantly. In conclusion, all safflower cultivars exhibit a commendable RFV. Nevertheless, the Olas and Linas cultivars outperformed the other cultivars. Additionally, from a harvest management perspective, budding period ensiling appears to be more suitable.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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