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ORIGINAL PAPER

Impact of different sucrose levels on silage fermentation quality and chemical composition of panicle-harvested quinoa*

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Abstract

Many studies have been conducted on evaluating quinoa as an alternative feed source through ensiling. However, there is no study available regarding the ensiling of quinoa by evaluating it as silage after harvesting the plant panicles in the early stage (45-50% DM) to obtain seeds. Therefore, in this study, silage fermentation quality and nutrient composition were investigated in the cultivars: Mint vanilla (cv. MV), Cherry vanilla (cv. CV), French vanilla (cv. FV), Red head (cv. RH), and Titicaca (cv. T) of quinoa containing high dry matter (QCHDM) using different sucrose doses (control, 20, 40, and 60 g kg^{-1} FM). The QCHDM cultivars were grown in a randomized complete block design with three replications. The seeds of the QCHDM cultivars were harvested, and the remaining leaves and stems were chopped using a plant chopping machine and ensiling was performed with 5 replicates. The fermentation characteristics and nutrient contents of the silages were investigated. All the silage fermentation characteristics were significantly influenced by cultivar and sucrose dose, but only the characteristics of lactic acid bacteria, ammonia nitrogen, lactic acid, and acetic acid were affected by the interactions of the variables. As the sucrose dose increased, it was determined that the desired improvement in silage fermentation characteristics occurred. Except for ether extract and dry matter, all the characteristics examined in the silage nutrient compositions were significantly affected by cultivar and sucrose dose treatments. On the other hand, there were interaction effects on such properties as neutral detergent fiber, acid detergent fiber, acid detergent lignin, and crude ash. Finally, it was concluded that adding sucrose at a dose of 60 g kg^{-1} FM to cv. FV of QCHDM could result in a higher quality silage in terms of fermentation quality and nutrient content. We have concluded that the findings of this study are highly significant in terms of dual-purpose quinoa cultivation.

Keywords: dual purpose, fermentation quality, high dry matter quinoa, nutritive value, silage

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INTRODUCTION

Quinoa (*Chenopodium quinoa* Willd.) is a plant native to the Andean region of South America, where it is a traditional food for the indigenous peoples of that area. In recent years, quinoa seeds, classified as pseudocereals, have garnered significant attention due to their exceptional nutritional value and potential health benefits (Vega-Gálvez et al. 2010). Quinoa seeds are rich in proteins, lipids, fibers, vitamins, and minerals. Additionally, these seeds contain various bioactive compounds that are highly beneficial for health. In addition to its high nutritional value, quinoa can survive in challenging conditions, tolerating a wide range of temperatures (-4 to 38°C), pH levels (6.0-8.5), low rainfall (50 mm per year), and high salinity levels (40 ms cm^{-1}) – Liu et al. (2021). Due to these characteristics, the plant can grow even in limited conditions. Compared to cereal crops, whole plant quinoa has a higher protein content and greater biomass yield (Basra et al. 2014, Shah et al. 2020). Therefore, according to many studies, it is emphasized that this plant may have alternative potential in animal feeding (Podkowka et al. 2018, Dong et al. 2022, Fang et al. 2022, Yilmaz et al. 2022, Ertekin et al. 2023). On the other hand, various studies have been conducted on the ensiling of this plant and its inclusion in animal feeding as silage (Podkowka et al. 2018, Dong et al. 2022, Ertekin et al. 2023), and certain silage making techniques have been recommended alongside some quinoa cultivars. The conversion of whole plant quinoa into silage without losing moisture, from an economic and practical perspective, is crucial for the preservation of this plant as feed.

The process of ensiling relies on anaerobic conditions for epiphytic lactic acid bacteria to utilize water-soluble carbohydrates (WSC), primarily producing various organic acids, including lactic acid (Ertekin, Kızılşimşek, 2020). This system creates an acidic environment to prevent spoilage in the silage material, thereby preserving the original quality of the moist silage material as much as possible. However, it has been reported that the WSC content and dry matter ratio in whole plant quinoa are lower than those used in silage production in corn and some cereals (Li, Nishino 2013, Ertekin et al. 2023, Akbay et al. 2023). The dry matter content and WSC content of the silage material are among the most important characteristics that can restrict the success of silage. Therefore, ensiling quinoa, which has low WSC content, with a sugar source during silage production may positively affect the silage quality. On the other hand, it has been reported that quinoa plants grown for seed production can be harvested slightly earlier, especially in humid regions, and the seeds can be obtained by drying them under controlled conditions (Sowiński et al. 2024). When the leaves of the quinoa plant begin to turn yellow and the entire plant changes color, the seeds start to mature (Stanschewski et al. 2021). After this stage, the dry matter content of the plant rapidly increases. Harvesting the seeds at this stage and taking advantage of the remaining biomass for feed purposes can be highly important for dual-purpose utilization. In this way, both quinoa seeds and an alternative feed source can be obtained.

The deficiency of WSC content in ensiled plant materials is addressed by using various WSC sources as additives. One of these sources is sucrose. Various studies have reported that sucrose can be effectively used as a WSC source in certain silage materials (Wang et al. 2021, Zi et al. 2022)

This study aimed to investigate the silage fermentation quality and nutrient composition of certain quinoa cultivars that have reached high dry matter content and have had their seeds harvested, by ensiling them with varying doses of sucrose supplementation.

MATERIALS AND METHODS

High dry matter quinoa (QCHDM) cultivars, silage material, and silage making

In this study, QCHDM cultivars (cv. Mint vanilla, cv. Cherry vanilla, cv. French vanilla, cv. Red head, cv. Titicaca) used as silage material were grown in separate plots at Hatay Mustafa Kemal University, Faculty of Agriculture, Field 49 Research and Application Area (located at 36°18′24″N 36°13′31″E, altitude 96 m). The QCHDM cultivars were grown in a randomized complete block design with three replications, under the same tillage, irrigation, and fertilization practices (60 kg ha^{-1} N, P, K applied at sowing and 60 kg ha^{-1} N applied 4 weeks after sowing). At the end of the 12^{th} week of growth, the seeds of the QCHDM cultivars were harvested, and the remaining leaves and stems were chopped using a plant chopping machine (CAN SP255, CANTEK MAKINA, Sinop, Türkiye). Samples were separated for the determination of epiphytic microflora population and initial nutrient content from the chopped samples. Each chopped QCHDM cultivar was divided into 4 groups and ensiled with sucrose doses of 0 (control), 20, 40, and 60 g kg^{-1} FM (fresh matter), with 5 replications, using a vacuum machine (CromPack VM 42 D, Istanbul, Türkiye) into polyvinyl bags (20-25 cm in size) containing approximately 400±40 g. Before ensiling, all silage materials were inoculated with *Lentilactobacillus buchneri* and *Lactiplantibacillus plantarum* bacteria (dose of 10^5 cfu g^{-1} FM). A total of 100 bags were stored in a climate chamber at 25°C and 70% relative humidity in dark conditions for 75 days.

Chemical and microbial analysis

After the ensiling process, the bags were opened (after 75 days), the silages belonging to the QCHDM cultivars were removed and thoroughly mixed in a plastic container. Three replicate samples of 100 g each were taken from samples. These samples were dried in a hot air oven cabinet (NÜVE KD 1400, Ankara, Türkiye) at 65°C for 48 h for chemical analysis. The dry matter (DM) content was determined from the difference between the fresh and dry weights of these samples. The dried samples were ground using a mill with a 1 mm sieve (Lavion HC-500, Istanbul, Türkiye) and prepared for chemical analysis. The ground samples were subjected to crude protein (CP), crude ash (CA), and ether extract (EE) analyses according to AOAC (2019) methods, with three replications. The neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) analyses of the silages and initial silage materials were conducted according to the method reported by Van Soest et al. (1991). The water-soluble carbohydrate (WSC) contents of the initial silage materials were determined using the phenol-sulfuric acid method (DuBois et al. 1956).

The 20 g sub-samples separated from silage and fresh plant samples were mixed with 180 mL of sterile Ringer solution and blended for 60 s using a blender (Arçelik K8130 MV, Istanbul, Türkiye). The mixed samples were filtered through Whatman No: 1 filter paper, and serial dilutions (from 10^{-1} to 10^{-10}) were prepared for microbial counts. The diluted filtrate samples were inoculated onto disposable sterile Petri dishes (90×15 mm) under sterile conditions. After inoculation, agar media (MRS Agar for lactic acid bacteria growth, MEA for yeast growth, VRB-G for enterobacteria growth) were added to the Petri dishes up to 20 mL, and then incubated in a water bath (WiseCircu WCB-22, Wonju, Kangwon-do, South Korea). Anaerobic conditions for lactic acid bacteria were provided by the addition of double-layered MRS-Agar medium to the Petri dishes. While the samples were incubated at 37°C for 48 h for lactic acid bacteria and yeast growth, they were then incubated at 33°C for 18 h for enterobacteria growth.

Silage pH and fermentation end products

Ammonia nitrogen (NH_3-N) and the contents of lactic acid (LA), acetic acid (AA), propionic acid (PA), butyric acid (BA), and ethanol (ETOH) were determined in the filtrates obtained by adding 180 mL of sterile Ringer solution to 20 g of fresh silage samples. NH_3-N was determined using distillation and titration methods based on the Kjeldahl (Behrotest S2 KAS20, Düsseldorf, Germany) procedure. The LA, AA, PA, BA, and ETOH contents of the silages were determined using a Shimadzu high-performance liquid chromatography system (Shimadzu KC-811, Kyoto, Japan) following sample cleanup, with a flow rate of 0.6 mL min^{-1} and a refractive index detector at 42°C, based on the method reported by Siegfried et al. (1984).

Data analysis

Chemical and microbial data obtained from fresh and ensiled QCHDM were subjected to one-way ANOVA using XLSTAT (version 14) statistical software. The differentiation between mean values was performed using the Tukey's pairwise test. Significant differences were reported when it was p<0.05.

RESULTS

Compositions of QCHDM cultivars before ensiling

When quinoa is offered fresh to livestock, animals do not prefer this feed, but any plant can be consumed by livestock when ensiled. As seen in Table 1, it was determined that there were differences ($p \leq 0.01$) in CA, CP, and WSC contents among the QCHDM cultivars, while no differences were found among the examined QCHDM cultivars for the other characteristics. The highest value for CA was obtained from cv. T, while cv. CV was statistically similar. The lowest CA content among the QCHDM cultivars was determined in cv. MV. The highest crude protein (CP) content among the quinoa cultivars used for silage production was obtained from cv. RH, while the lowest was in cv. CV. In terms of silage quality, cv. FV had the highest WSC content. The lowest WSC content was detected in cv. RH, and the other QCHDM cultivars except cv. FV were statistically in the same group.

Table 1

The DM content and chemical and microbial composition of freshly chopped QCHDM cultivars before ensiling

Items	Cultivars					SEM	*p*-values
	MV	CV	FV	RH	T		
DM (%)	47.50	48.23	42.98	46.84	45.05	1.62	0.35
NDF (% DM)	33.85	37.80	35.27	36.12	37.71	0.86	0.11
ADF (% DM)	17.97	20.26	18.57	18.81	19.23	0.56	0.33
ADL (% DM)	3.64	3.83	3.71	3.97	3.95	0.15	0.58
CA (% DM)	10.12^{c}	11.34^{ab}	10.73^{bc}	10.65^{bc}	12.01^{a}	0.18	<0.01
CP (% DM)	12.82^{ab}	10.96^{b}	12.21^{ab}	12.97^{a}	12.66^{ab}	0.33	0.05
WSC (% DM)	8.38^{b}	8.52^{b}	9.43^{a}	8.24^{b}	8.53^{b}	0.17	<0.01
EE (% DM)	2.36	2.34	2.32	2.26	2.25	0.03	0.12
LAB ($\log_{10}$cfu g^{-1} DM)	2.09	2.18	2.22	2.17	2.13	0.03	0.17
ENT ($\log_{10}$cfu g^{-1} DM)	4.12	4.27	4.36	4.22	4.32	0.05	0.06
Yeast ($\log_{10}$cfu g^{-1} DM)	3.59	3.57	3.62	3.62	3.57	0.04	0.72

MV – Mint vanilla, CV – Cherry vanilla, FV – French vanilla, RH – Red head, T – Titicaca, DM – dry matter, NDF – Neutral detergent fiber, ADF – Acid detergent fiber, ADL – Acid detergent fiber, CA – Crude ash, CP – Crude protein, WSC – Water soluble carbohydrate, EE – Ether extract, LAB – Lactic acid bacteria, ENT – Enterobacteria, SEM – Standard error mean. The different superscripts in each line indicate a significant difference by the Tukey's pairwise test at the adopted *p*-value.

Main effects on silage fermentation properties and microbial compositions

The data and statistical analysis results for silage fermentation characteristics and microbial compositions are presented in Table 2. It was determined that all examined fermentation and microbial properties were significantly affected by both cultivars and sucrose doses at the main effect level (p<0.01). However, pH, yeast, PA, BA, and ETOH characteristics were influenced only by the main variables, while the others were affected by interactions as well. Therefore, the main effects of the characteristics affected by interactions have been disregarded. The pH levels varied between 4.02 and 4.16 among the cultivars. The lowest pH level for best silage quality was determined in cv. FV. As the sucrose dose increased, the pH levels of the silages decreased. The lowest silage pH level (3.99) was observed with the application of 60 g kg^{-1} FM sucrose. No ENT count was detected in the silages. While the highest yeast count among cultivar treatments was determined in cv. MV, the other QCHDM cultivars except cv. FV were statistically similar. The lowest yeast count was detected in cv. FV. Along with an increasing sucrose dose, the yeast counts in the silages also increased. Among cultivars, silage PA contents varied between 0.61% DM and 0.72% DM. The highest silage PA content was detected in cv. CV, and cv. RH and cv. T were statistically similar. The lowest silage PA content was in cv. FV. Increasing sucrose doses decreased the PA contents of the silages. Among cultivar treatments, the highest BA content (0.35% DM) was detected in cv. T, while the lowest BA content (0.28% DM) was found in cv. MV. As the sucrose dose increased, the BA contents of the silages declined. Among cultivars, silage ETOH contents varied between 0.91% DM and 0.97% DM. The highest ETOH content was observed in cv. MV, while the lowest ETOH content was in cv. T. As the sucrose dose as a silage additive increased, the ETOH contents of the silages also improved. With the treatment of 60 g kg^{-1} FM sucrose, an ETOH content of 1.08% DM was detected.

Main effects on silage DM and chemical compositions

The data and statistical analysis results for silage DM and chemical compositions are given in Table 3. As seen in Table 3, the effect of cultivars on silage DM was significant (P<0.01), while the effect of sucrose doses was insignificant (P=0.98). Except for the EE, both the effects of cultivars and sucrose doses were found to be significant (P≤0.01) on the investigated chemical composition properties. Only the effect of cultivars was found to be significant on the EE content. Due to the significant impact of interactions on the NDF, ADF, ADL, and CA characteristics, the main effects on these properties have been disregarded. The highest DM (47.10%) was observed in cv. T, while the lowest (39.35%) was in cv. FV. The cultivar with the highest CP content was observed to be cv. T, with 11.77% DM, while the lowest was observed to be cv. FV, with 10.40% DM. Increasing sucrose doses were asso-

Table 2

Silage fermentation properties and microbial compositions according to main effects of cultivars and sucrose doses

Items	Cultivars (V)					Sucrose doses (SD)				SEM			p-values		
	MV	CV	FV	RH	T	C	20	40	60	V	SD	V×SD	V	SD	V×SD
pH	4.07^{b}	4.16^{a}	4.02^{c}	4.12^{ab}	4.16^{a}	4.21^{a}	4.15^{b}	4.07^{c}	3.99^{d}	0.03	0.02	0.02	<.01	<.01	0.44
LAB	4.80^{a}	4.47^{c}	4.76^{a}	4.64^{b}	4.83^{a}	4.35^{d}	4.60^{c}	4.80^{b}	5.06^{a}	0.08	0.05	0.04	<.01	<.01	<.01
ENT	nd	nd	nd	nd	nd	nd	nd	nd	nd	-	-	-	-	-	-
Yeast	1.28^{a}	1.27^{a}	1.21^{b}	1.27^{a}	1.26^{a}	1.11^{d}	1.24^{c}	1.31^{b}	1.37^{a}	0.03	0.01	0.02	0.01	<.01	0.74
NH_3-N	8.67^{c}	9.92^{a}	8.54^{d}	9.27^{b}	8.75^{c}	9.65^{a}	8.97^{b}	8.83^{c}	8.68^{d}	0.12	0.14	0.05	<.01	<.01	<.01
LA	3.91^{a}	3.34^{d}	3.84^{b}	3.44^{c}	3.34^{d}	3.34^{d}	3.49^{c}	3.60^{b}	3.87^{a}	0.06	0.07	0.03	<.01	<.01	<.01
AA	1.49^{c}	1.56^{ab}	1.36^{d}	1.57^{a}	1.52^{bc}	1.36^{d}	1.46^{c}	1.54^{b}	1.64^{a}	0.03	0.02	0.02	<.01	<.01	<.01
PA	0.66^{b}	0.72^{a}	0.61^{c}	0.71^{a}	0.70^{a}	0.78^{a}	0.70^{b}	0.65^{c}	0.60^{d}	0.02	0.01	0.01	<.01	<.01	0.06
BA	0.28^{b}	0.33^{a}	0.30^{b}	0.33^{a}	0.35^{a}	0.36^{a}	0.34^{a}	0.30^{b}	0.27^{c}	0.01	0.01	0.01	<.01	<.01	0.99
ETOH	0.97^{a}	0.92^{b}	0.93^{ab}	0.95^{ab}	0.91^{b}	0.79^{d}	0.89^{c}	0.98^{b}	1.08^{a}	0.03	0.01	0.02	<.01	<.01	0.16

MV – Mint vanilla, CV – Cherry vanilla, FV – French vanilla, RH – Red head, T – Titicaca, LAB – Lactic acid bacteria (log_{10}cfu g^{-1} DM), ENT – Enterobacteria (log_{10}cfu g^{-1} DM), NH_3-N – Ammonia nitrogen (% TN), LA – Lactic acid (% DM), AA – Acetic acid (% DM), PA – Propionic acid (% DM), BA – Butyric acid (% DM), ETOH – Ethanol (% DM), SEM – Standard error mean, nd – not detected. The different superscripts in each line indicate a significant difference by the Tukey's pairwise test at the adopted p-value.

Table 3

Silage DM and chemical compositions according to main effects of cultivars and sucrose doses

Items	Cultivars (V)					Sucrose doses (SD)				SEM			p-values		
	MV	CV	FV	RH	T	C	20	40	60	V	SD	V×SD	V	SD	V×SD
DM	46.64^{a}	47.03^{a}	39.35^{b}	46.56^{a}	47.10^{a}	45.43	45.15	45.42	45.36	0.75	1.05	1.38	<.01	0.98	0.36
NDF	29.88^{b}	28.90^{c}	29.28^{bc}	30.77^{a}	29.31^{bc}	30.58^{a}	30.79^{a}	28.62^{b}	28.53^{b}	0.78	0.66	0.34	<.01	<.01	<.01
ADF	18.14^{b}	17.47^{c}	17.46^{c}	19.29^{a}	18.07^{b}	18.51^{b}	18.95^{a}	17.35^{c}	17.54^{c}	0.49	0.43	0.22	<.01	<.01	<.01
ADL	3.34^{bc}	3.60^{a}	3.53^{ab}	3.36^{bc}	3.25^{c}	3.61^{a}	3.53^{a}	3.31^{b}	3.20^{b}	0.10	0.09	0.10	<.01	<.01	<.01
CP	11.34^{a}	10.97^{ab}	10.40^{b}	10.92^{ab}	11.77^{a}	11.41^{a}	11.40^{a}	10.91^{ab}	10.59^{b}	0.21	0.21	0.25	<.01	0.01	0.80
CA	10.54^{b}	10.56^{b}	11.32^{a}	11.21^{a}	11.34^{a}	11.39^{a}	11.30^{a}	10.62^{b}	10.66^{b}	0.16	0.15	0.10	<.01	<.01	<.01
EE	2.35^{a}	2.33^{ab}	2.32^{ab}	2.26^{bc}	2.23^{c}	2.30	2.29	2.30	2.29	0.02	0.02	0.03	<.01	0.97	0.99

MV – Mint vanilla, CV – Cherry vanilla, FV – French vanilla, RH – Red head, T – Titicaca, DM – dry matter (%), NDF – Neutral detergent fiber (% DM), ADF – Acid detergent fiber (% DM), ADL – Acid detergent fiber (% DM), CP – Crude protein, CA – Crude ash (% DM), EE – Ether extract (% DM), SEM – Standard error mean. The different superscripts in each line indicate a significant difference by the Tukey's pairwise test at the adopted p-value.

ciated with a decreasing trend in silage CP content. The EE contents of silages varied between 2.23% DM and 2.35% DM among the cultivars. The highest EE content was observed in cv. MV, while the lowest was found in cv. T.

Interaction effects on silage LAB, NH_3-N, LA, and AA characteristics

The LAB, NH_3-N, LA, and AA parameters were significantly affected by the interaction of cultivars×sucrose doses (P<0.01) – Table 2. The results of the LAB, NH_3-N, LA, and AA characteristics arising from interactions are given in Figure 1. When examining the LAB count values, the lowest LAB

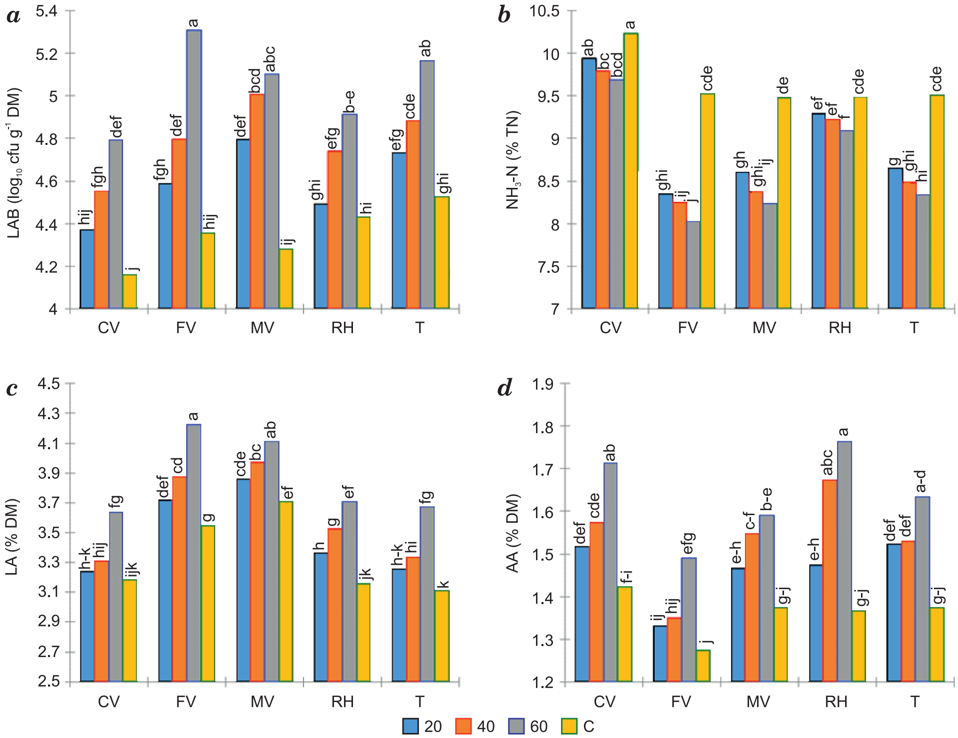

Fig. 1. Changes of LAB, NH_3-N, LA, and AA contents with the interaction effects of cultivars and sucrose doses

count was observed when no sucrose was added to all cultivars, while the highest LAB count was determined with the application of the highest sucrose dose of 60 g kg^{-1} FM. The highest LAB count was determined in cv. FV with the addition of 60 g kg^{-1} FM sucrose (Figure 1*a*). The NH_3-N contents decreased in all cultivars in response to the increasing sucrose dose. When examining Figure 1*d*, it is observed that particularly in the FV, MV, and T cultivars, the NH_3-N content significantly decreased with sucrose doses compared to the C treatment. The lowest NH_3-N content was determined in cv. FV with the addition of 60 g kg^{-1} FM sucrose (Figure 1*b*). The LA contents of all cultivars were found to be the lowest in the C treatment and the highest in the treatment with 60 g kg^{-1} FM sucrose dose. The highest LA content occurred when 60 g kg^{-1} FM sucrose was added to cv. FV (Figure 1*c*). Under the interaction effect, the AA contents of the cultivars varied, and the AA contents of all cultivars increased as the sucrose dose increased. The lowest AA content was determined in cv. FV with the C application. The highest AA content, however, occurred in cv. RH with the addition of 60 g kg^{-1} FM sucrose dose (Figure 1*d*). Overall, cv. FV had a lower AA content compared to other varieties at all sucrose doses.

Interaction effects on silage NDF, ADF, ADL, and CA characteristics

The NDF, ADF, ADL, and CA parameters were significantly affected by the interaction of cultivars×sucrose doses (P<0.01) – Table 3. The interaction graphs for the significant characteristics are provided in Figure 2. When examining the silage NDF contents under the interaction effect, we observed that the highest silage NDF content was obtained when 20 g kg^{-1} FM suc-

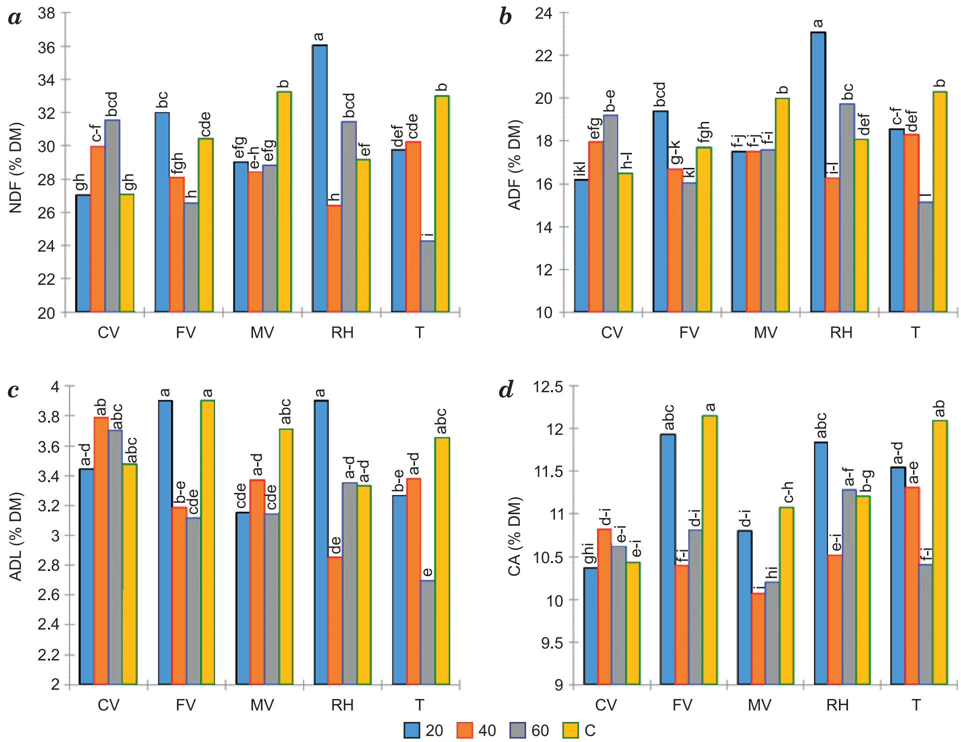

Fig. 2. Changes of NDF, ADF, ADL, and CA contents with the interaction effects of cultivars and sucrose doses

rose dose was treated to cv. RH, while the lowest was determined when 60 g kg^{-1} FM sucrose dose was treated to cv. T (Figure 2*a*). Similar to the NDF contents, similar results have been obtained in the silage ADF content as well. Here again, for the highest silage ADF content, treatment with 20 g kg^{-1} FM sucrose dose to cv. RH and for the lowest, treatment with 60 g kg^{-1} FM sucrose dose to cv. T were prominent (Figure 2*b*). Similar to the silage NDF and ADF contents, it is possible to say that the same results also occurred in the silage ADL content (Figure 2*c*). Indeed, the highest and lowest ADL contents were respectively determined in cv. RH with 20 g kg^{-1} FM sucrose dose and cv. T with 60 g kg^{-1} FM sucrose dose additions (Figure 2*c*). In terms of silage CA content, cv. FV and cv. T yielded similar results with the C treatment, while other cultivars exhibited lower silage CA content in all sucrose dose treatments (Figure 2*d*).

DISCUSSION

The QCHDM properties before ensiling

The CA, CP, and WSC contents were significantly affected by the QCHDM cultivars. According to several studies conducted to date, it has been reported that there may be variations in the CA, CP contents among different cultivars (Leto et al. 2004, Ayub et al. 2012, Akdeniz et al. 2019). Similarly, it has been reported that the amount of WSC present in the plant varies among plant species and cultivars (Sanada et al. 2004, Easton et al. 2009, Amer et al. 2012, Jafari, 2012, McGrath et al. 2014). This study's findings regarding both CA and WSC content are supportive of the literature reports.

Silage fermentation characteristics and microbial compositions

The pH levels of all cultivars exhibited a decreasing trend with an increasing sucrose dose. In terms of silage quality, a pH range between 3.6 and 4.2 is considered tolerable (Kung 2010). A low pH in silage is always a desired characteristic for silage quality (Driehuis 2013). The silage pH values obtained from this study have been determined to be at a sufficient level for good silage quality, as reported in the literature. Additionally, it has been concluded that silage pH could be further improved by using sucrose supplementation. Similar to silage pH levels, the LAB counts in silages of all QCHDM cultivars increased with increasing sucrose dose. Various studies have demonstrated that excessively high DM ratios adversely affect LAB proliferation in silages (Borreani et al. 2018, da Silva et al. 2022). Indeed, silages of QCHDM cultivars with higher initial DM contents had lower LAB counts. With the increase in the sugar source in silages, the yeast counts in the silages also increased. The yeast content in silage is one of the factors that negatively affects silage quality, and yeast content in silage is an undesirable characteristic (Kung, 2018, Kung et al. 2018). From this perspective, it has been determined in present study that cv. FV produced better silage compared to other cultivars in all sucrose dose treatments. With different sucrose doses, cv. FV has yielded lower NH_3-N content compared to other QCHDM cultivars. High NH_3-N content in silage is an undesirable condition, indicating significant protein degradation in silage (Kung et al. 2018). Based on this information, it can be said that among all QCHDM cultivars, cv. FV is superior in all sucrose levels. In all QCHDM cultivars, silage LA content improved with an increasing sucrose dose. Having a high LA content in silage is crucial for silage quality, and silage LA contents can be significantly influenced by the initial contents of the silage starting material (Kung et al. 2018). As seen in Table 1, the WSC content of cv. FV cultivars was found to be higher than of the other QCHDM cultivars, which may have led to a higher LA content. It has been determined that all QCHDM cultivars indicated variations in silage AA contents with different sucrose doses. Various studies have determined that the silage AA content varied among different plant species and cultivars (Mustafa et al. 2002, Pinho et al. 2015, Zheng et al. 2018, Ertekin et al. 2022). Indeed, similar results have been obtained from present study as well. Among all sucrose dose applications, cv. FV from the QCHDM cultivars presented lower PA content. It has been reported that silage PA contents can vary depending on the initial WSC content of plant cultivars and the dose of sugar source used before ensiling (Pinho et al. 2015, Kung et al. 2018). The PA contents obtained from the silages in the current study support this information. It has been determined that the QCHDM cultivars and all sucrose dose treatments showed differences in BA contents. Various studies have reported that silage BA contents varied with different doses of sugar sources (Heinritz et al. 2012, Zheng et al. 2018, Kang et al. 2021, Zi et al. 2022). It has been determined that the ETOH content of silages in all the QCHDM cultivars and sucrose doses varied. Similar results have been reported in various studies where different sugar sources were used as additives (Heinritz et al. 2012, Kang et al. 2021, Zi et al. 2022).

Silage DM and chemical compositions

The composition of silage DM varied depending on all QCHDM cultivars. The lowest silage DM content was identified in cv. FV across all sucrose doses. Similarly, Demirel et al. (2011) have observed that silage DM contents are influenced by cultivars and exhibit variability. Silage NDF and ADF contents of QCHDM cultivars also varied with different sucrose doses. Various studies have reported that silage NDF and ADF contents may vary depending on cultivars (Demirel et al. 2011, Neves et al. 2015, Pinho et al. 2015). On the other hand, it has been reported that during the initial stages of fermentation in silage, certain microorganisms can alter silage NDF and ADF contents by enzymatic activity (Kung et al. 2018, Zhao et al. 2019).

Additionally, the results obtained for both ADF and NDF were determined to be at ideal levels for animal nutrition. The variation in morphological characteristics among plant species may have contributed to this outcome (Demirel et al. 2011). Similarly, it has been reported that silage ADL contents are influenced by the interaction impacts. Indeed, the silage NDF, ADF, and ADL contents obtained from present study exhibit similarities with numerous literature reports. The CP contents of the QCHDM cultivars have been affected by the cultivars and sucrose doses. Several studies have reported variations in silage CP contents depending on cultivars (Demirel et al. 2011, Neves et al. 2015, Pinho et al. 2015). Additionally, in some studies, differences in silage CP content have been observed with the use of sugar sources as additives (Chen et al. 2020). It has indicated that during the initial stages of fermentation, some microorganisms can break down proteins in silage into ammonia nitrogen, leading to a decrease in silage CP content (Kung et al. 2018). The silage CP contents obtained from this study were similar to literature reports. Variations in silage CA contents attributable to interaction may result from differences in the CA contents of cultivars (see Table 1). Indeed, in many studies, differences in silage CA content among plant cultivars classified as silage have been reported, resulting in variations in the CA contents of silages obtained from these cultivars (Demirel et al. 2011, Neves et al. 2015, Pinho et al. 2015). The CA contents obtained in this study were found to be higher than those of wheat (Ertekin 2023) and nearly similar to those of alfalfa and annual ryegrass (Ertekin, Kızılşimşek 2020, Ertekin et al. 2022). This may be attributed to the morphological differences of the plant.

CONCLUSIONS

In present study, the fermentation characteristics, and nutrient contents of panicle harvested QCHDM cultivars (at 45-50% DM) were investigated when ensiled with different sucrose doses. With an increasing sucrose dose, the silage fermentation characteristics of all the QCHDM cultivars were shown the desired improvement. The best silage in terms of fermentation quality was obtained when a sucrose dose of 60 g kg^{-1} FM was applied to cv. FV. Cv. T was provided a higher quality nutrient content in all sucrose dose treatments. However, particularly in terms of CP, cv. FV was statistically provided results similar to cv. T. Based on the results obtained in this study, if we make this recommendation, adding sucrose at a dose of 60 g kg^{-1} FM to cv. FV of QCHDM could result in a higher quality silage both in terms of fermentation quality and nutrient content. This study provides crucial results for dual-purpose production in quinoa.

Author contributions

I.E. and I.A. – conceptualization, data curation, formal analysis, investigation and methodology; I.E. – project administration, resources and software; I.A. and E.C. – supervision and visualization; I.E., I.A. and E.C. – writing – original draft preparation and writing – review & editing. All authors have read and agreed to the published version of the manuscript.

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Conflicts of interest

The author has declared that no competing interests exist.

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