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Determination of quality and nutrient content of artichoke by-products ensilaged with barley and molasses

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ABSTRACT. The aim of this study was to determine the nutrient composition and quality of artichoke by-products ensiled with barley and molasses. Artichoke by-products included leaf, bracts and stalks of plants. Materials for ensiling were prepared from artichoke by-products without any additives (control silage), or with barley and molasses in the amounts of 2.5% and 5%, respectively. The prepared materials were ensiled in jars, incubated, and then the nutrient contents, selected fermentation parameters, and *in vitro* dry matter digestibility (IVDMD) of these silage samples were determined. Barley and molasses supplementation increased dry matter, organic matter, IVDMD, pH, lactic and acetic acid values of the silage from artichoke by-products ($P < 0.05$). However, the content of crude protein, ash, neutral detergent fibre and acid detergent fibre decreased in artichoke by-product silage due to barley and molasses supplementation ($P < 0.05$). In addition, it was determined that propionic acid and ammonia-N levels were similar between the groups ($P > 0.05$), but butyric acid did not occur at all. In vitro ruminal energy (metabolisable energy and net energy lactation) and IVDMD values of artichoke by-product silages with additives were higher than those of the control silage. As a result, it has been concluded that it is possible to produce similar silages to maize silage from green/fresh artichoke by-products in terms of both organoleptic properties and nutrient content. Moreover, it was also observed that supplementing the silage material with barley and molasses additives significantly improved silage quality.

Introduction

The main product of artichoke plant (*Cynara scolymus* L.) is its "flower heads", which are used as an edible vegetable, and add richness to the Mediterranean cuisine. However, it is also a source of medicinal food that can play an important role in both human nutrition and health protection thanks to the presence of polyphenolic and flavonoid compounds, which show liver-protective, lipid metabolism-balancing, anticarcinogenic, antibacterial and antioxidant effects (Lattanzio et al., 2009; Christaki et al., 2012); they additionally contain inulin, a compound with prebiotic properties (Pandino et al., 2011), and a wide range of vitamins and minerals (De Falco et al., 2015). It is an important agricultural product that is grown in Türkiye, especially in the Aegean, Marmara and partly in the Mediterranean regions, and has a high economic profitability (Bektas and Saner, 2013). It was reported that 40 114 tonnes of artichoke plant were produced on an area of 2 818 hectares in Türkiye in 2021 (TUIK, 2021).

Structurally, the artichoke is a plant species with annual aerial (shoot) and perennial underground (root) organ systems (De Falco et al., 2015). Therefore, artichokes have the ability to regenerate shoot systems and produce yield every year, as long as their roots do not lose their vitality. Considering this feature of the plant, it can be observed that the aerial structures left in the fields after harvest are not utilized in any way (if not left for seed production) and are mostly left to dry. In this case, an idea may arise not to waste the plant remains, but to use them in some way and bring them into the economy. Considering that these materials are an agricultural product residue, their usability as an alternative forage material and their nutritional properties should be investigated to support this idea. In fact, studies, albeit limited, have shown that it is possible to produce silage feed from artichoke by-products with very suitable physical properties and good quality (Gul et al., 2001; Meneses et al., 2007; Monllor et al., 2020; Fan et al., 2020). Evaluated in terms of animal nutrition, it has been reported that ruminants willingly consume artichoke silage, thus it can be easily used at doses of up to 25–30% without compromising meat and milk quality (dry matter, fat, protein), animal performance, and without jeopardizing their health status (Marsico et al., 2005; Jaramillo et al., 2010; Pizarro et al., 2019).

The aim of this study was to determine whether artichoke leaves and stems left in the fields after harvesting flower heads, could be used as silage material for animal nutrition and whether they could be introduced into the economy by enriching with barley and molasses.

Material and methods

The experiment used leafy artichoke stalks as silage material, which are grown in agricultural production areas of the Urla district of İzmir city.

The silage material, i.e. the green leafy stalks left in the fields after the harvest of the artichoke flower heads, was manually chopped into about 0.5–3 cm pieces, and subsequently compressed by hand into one-litre glass jars, airtight sealed and left for fermentation. Artichoke by-products included the leaves, bracts and stalks of plants. Five individual groups were formed in the experimental design. Fresh artichoke by-products were ensiled without additives (control group C), and with crushed barley grain (2.5% and 5%, groups B1 and B2, respectively) or sugar beet molasses (2.5% and 5%, groups M1 and M2, respectively) added to the wet material. The silage for each group was prepared in three replicates and stored for 3 months under normal daily temperature conditions.

After the fermentation process, the silage jars were opened, and 25 g of wet silage samples were taken from each jar, 100 ml of distilled water was added and the samples were homogenised in an electric chopper (MMR15A1, Robert Bosch Hausgeräte GmbH, Ljubljana, Slovenia). The homogenates were passed through filter papers. The pH value of the filtered silage samples was determined using a digital pH meter (Hanna HI 2211, Hanna Instruments Inc., Nusfalau, Romania). Ammonia-N concentrations in the filtered silage samples were determined using the Kjeldahl distillation method described by Filya (2003). Ten millilitres of the filtered silage juices were transferred into capped plastic tubes for the determination of lactic and volatile fatty acids (acetic, propionic, and butyric acids) and stored in a freezer at −18 °C until analysis. The remaining wet silage samples were dried and stored at room temperature and subsequently ground and analysed to determine their chemical compositions.

The dry matter (DM), crude protein (CP) and ash contents of the silages were determined according to Weende analysis methods (AOAC International, 2005). Neutral detergent (NDF) and acid detergent fibre (ADF) values were determined using a fibre analyser (Ankom 200 Fiber Analyzer, Ankom Technology, Macedon, NY, USA) according to the method reported by Van Soest et al. (1991). To determine silage quality, Flieg scores were calculated according to the equation given by Kilic (1986). *In vitro* dry matter digestibility (IVDMD) was analysed and determined using an *in vitro* incubator (Daisy Incubator, Ankom Technology, Macedon, NY, USA) according to the manufacturer's instructions (Ankom, 2021). Metabolic energy (ME) and net energy lactation (NE_L) values for ruminants were calculated according to NRC (2001), based on the determined *in vitro* dry matter digestibility values.

The lactic acid (LA) content in silage fluid was determined according to the modified spectrophotometric method of Barnett (1951) (Tekin and Kara, 2020). The amount of LA in the sample fluid was calculated as lactate equivalent from the calibration curve (R^2 = 0.95) of standard lithium lactate (0.312–160 µg/ml). Silage fluid mixed (5:1 ratio) with meta-phosphoric acid (25%, w/v) in an Eppendorf tube was centrifuged at 15 000 rpm for 15 min using a microcentrifuge (Gyrozen 1524, Gyrozen

Co. Ltd, Daejeon, Republic of Korea). The analysis of volatile fatty acids (VFAs) (acetic (AA), butyric (BA), and propionic acids (PA)) in silage fluid was measured using a gas chromatograph (GC, Thermo Trace 1300, Thermo Scientific, Waltman, MA, USA) (Ersahince and Kara, 2017). Based on the retention time and peak area on the chromatograms, VFA concentrations (mmol/l) were determined using Xcalibur software (Thermo Scientific, Waltman, MA, USA). The percentage concentrations of VFAs in silage DM were calculated.

Statistical analyses of the data were carried out using the SPSS© 15.0 package software. Analysis of variance (one-way ANOVA) was used to determine significance between experimental groups and means were separated by Duncan's test ($P < 0.05$).

Results and discussion

The nutrient contents in the silage samples prepared in the experiment are shown in Table 1, *in vitro* IVDMD, ME and NE_L values are presented in Table 2, and silage fermentation parameters are listed in Table 3. After analysing the data, it was found that there were statistically significant differences between the silage groups in nutrient contents, *in vitro* DM digestibility and calculated energy parameters, as well as important fermentation products (pH, lactic and acetic acids), with the exception of propionic acid. Almost all parameters tested in the silages showed statistical differences between the groups in the current study.

Chemical content parameters

The highest DM value was determined in group M2 (19.00%), while the lowest (14.99%) in the control group ($P < 0.05$) (Table 1). Based on these results, the DM percentages of the silage were similar and consistent with the 16.70% DM value reported by Marsico et al. (2005) for fresh/green artichoke residues (bract leaf), 15.6% reported by Megias et al. (1997), 16.21% by Konca et al. (2005), and 19.00% by Monllor et al. (2020) for artichoke by-product silage without additives. Moreover, the DM ratios of silages produced from some agro-industrial by-products appeared to be similar to the silage from artichoke by-products, ranging from 14.21 to 16.09% in non-supplemented sugar beet pulp silage (Sahin et al., 1999), sugar beet leaf silage (Can et al., 2003), broccoli by-product silage (Monllor et al., 2020), tomato herbage silage (Tekin and Kara, 2020), and fruit by-product (apple, peach, apricot) pulp silages (Yalcinkaya et al., 2012). However, it was shown that these rates could be increased by adding molasses, wheat, potato pulp, etc. to silage materials (Gul et al., 2001; Can et al., 2003; Senyuz and Karsli, 2021).

After examining the OM percentages (Table 1), it was observed that group B2 (87.99%) had the highest, while the control group (84.01%) the lowest percentage of OM. Monllor et al. (2020) determined the OM value at 91.6% in artichoke by-product silage. According to the present results, it could be concluded that the addition of barley and molasses to the silage material increased the DM and OM values gradually and in parallel with the increasing levels of additives compared to group C. Moreover, in studies involving agricultural industry by-products, Can et al. (2003) determined the percentage of OM to be 79.11% in non-supplemented sugar beet leaf silage (this proportion increased in silages with molasses and wheat additives), 82.1% in broccoli by-product silage (Monllor et al., 2020), and 94.55% in potato pulp silage (Senyuz and Karsli, 2021); therefore, the OM value of artichoke by-product silage in the current study was comparable to the aforementioned products. On the other hand, it was found that the OM value of artichoke by-product silage was much higher than the range of 13.60–14.46% reported by Yalcinkaya et al. (2012) for apple, peach and apricot pulp silages. This was likely due to the fact that the artichoke is a plant that retains high moisture levels in its body and can lose a lot of weight when left to dry. Jaramillo et al. (2010) also emphasized this feature of artichoke and stated that it significantly reduced the daily DM intake when fed to animals in this form (i.e., wet/green or silage). In summary, the present study demonstrated that the addition of barley and molasses to artichoke silage could significantly improve the DM and OM values of silage samples due to the higher DM and OM levels of these additives. In fact, Gul et al. (2001) has also voiced a similar opinion. It should be remembered that plain artichoke silage can be enriched in nutrients with additives, but due to the low DM level, when preparing total mix ration, it should be considered that such silages may adversely affect the daily DM consumption of the animal by lowering the DM value in the total ration.

Analysing CP percentages in silages in the presented study, it was noted that while the CP percentage was the highest in group C (12.30% DM), it was significantly lower in the groups supplemented with molasses (10.22–10.43%) and barley (10.89–11.27%) (Table 1). The CP percentages in artichoke silages without any additives were previously reported to range from 6.88% to 14.5%

Table 1. Chemical content of silages, DM%

Parameters	Groups					*P*-value
	C	B1	B2	M1	M2	
DM	14.99[c] ± 0.21	15.41[c] ± 0.24	17.45[b] ± 0.43	16.59[b] ± 0.50	19.00[a] ± 0.35	<0.01
OM*	84.01[d] ± 0.37	86.26[b] ± 0.10	87.99[a] ± 0.33	85.37[c] ± 0.06	85.76[bc] ± 0.03	<0.01
Ash*	15.99[a] ± 0.37	13.74[c] ± 0.10	12.01[d] ± 0.33	14.63[b] ± 0.06	14.24[bc] ± 0.03	<0.01
CP*	12.30[a] ± 0.26	10.89[bc] ± 0.11	11.27[b] ± 0.24	10.22[d] ± 0.14	10.43[cd] ± 0.18	<0.01
NDF*	30.14[a] ± 0.65	29.97[a] ± 0.86	28.55[ab] ± 0.59	27.04[b] ± 0.30	25.07[c] ± 0.58	<0.01
ADF*	23.02[a] ± 0.24	22.38[ab] ± 0.67	20.90[bc] ± 0.74	21.13[bc] ± 0.23	19.72[c] ± 0.48	<0.01

C – control, B1 – 2.5% crushed barley grain, B2 – 5% crushed barley grain, M1 – 2.5% sugar beet molasses, M2 – 5% sugar beet molasses; DM – dry matter, OM – organic matter, CP – crude protein, NDF – neutral detergent fibre, ADF – acid detergent fibre; * determined based on dry matter; data are presented as mean value ± SEM (standard error of the mean); [a–d] – means within a row with different superscripts are significantly different at $P < 0.05$

(Megias et al., 1997; Gul et al., 2001; Konca et al., 2005; Meneses et al. 2005; 2007; Monllor et al., 2020). The CP value of artichoke silage was found to be slightly better when compared to cereal silages commonly used in ruminant feeding. In fact, it was reported that the CP value in maize and triticale grass silages were in the range of 4.97–10.43% (Konca et al., 2005). When compared with agro-industrial by-product silages, the CP results obtained in the study were lower than for the non-supplemented sugar beet leaf (22.29%) and broccoli by-product silages (17.4%), similar to tomato grass silages (12.31%), slightly better than for sugar beet (8.41%) and potato pulp (7.97%), while at significantly higher levels compared to fruit pulp silages (1.03–1.70%) such as apple, peach, apricot, etc. (Sahin et al., 1999; Can et al., 2003; Yalcinkaya et al., 2012; Monllor et al., 2020; Tekin and Kara, 2020; Senyuz and Karsli, 2021). Although the addition of molasses and barley slightly reduced the protein level of the artichoke residue silage, the protein content was still higher compared to silages obtained from cereal grains. Thus, when evaluated in terms of protein content, artichoke residues are a good forage alternative to silages obtained from grass grains.

The proportion of NDF and ADF was the highest in group C (NDF 30.14% and ADF 23.02%), but it significantly decreased (linearly) with the addition of molasses (NDF 25.07–27.04% and ADF 19.72–21.13%); there was also a decreasing trend observed in the groups with the addition of barley (Table 1). In the literature, crude fibre (CF) content in non-supplemented artichoke silage was reported to range from 34.13% to 50.9% (Gul et al., 2001; Konca et al., 2005; Meneses et al., 2007). The NDF and ADF values in artichoke by-product silages without additives were reported to amount to 64.2% and 41.8% (Megias et al., 1997), and 52.8% and 35.4% (Monllor et al., 2020), respectively. However, these figures are almost 1.5 to 2 times higher than those obtained in the present study. This difference seemed to be due to different artichoke plant varieties applied in individual studies. However, in comparison with other silages from plant residues, the NDF and ADF values obtained in the presented study were comparable to the non-supplemented sugar beet leaf (31.33% and 12.80% for NDFs and ADFs, respectively), tomato herbage (24.72% vs 23.23%) and potato pulp (32.07% vs 17.15%) silages, lower than in broccoli by-product silage (43.0 vs 32.6%), but markedly higher compared to fruit pulp (apple, peach, apricot, NDF 7.70–8.58% and ADF 6.50–7.63%) silages (Can et al., 2003; Yalcinkaya et al., 2012; Monllor et al., 2020; Tekin and Kara, 2020; Senyuz and Karsli, 2021). Since the NDF and ADF contents of molasses and barley were very low compared to artichoke residues (NRC, 2001), it was expected that the NDF and ADF contents of the silages would be accordingly reduced with the addition of increasing molasses and barley concentrations to artichoke residues. Therefore, the NDF and ADF values obtained for artichoke silages in the current study were lower than those reported in the literature, but they were similar or higher than the values published for cereal grain silages.

In vitro digestibility and energy parameters

Although the highest *in vitro* DM digestibility was recorded in groups M (83.80–84.58%), the addition of both barley and molasses to artichoke by-product significantly improved silage IVDMD ($P < 0.05$) (Table 2). The IVDMD of artichoke by-product silage was previously reported to be 82.1% (Meneses et al., 2020), and 76.9% (Monllor et al., 2020), but this value for the artichoke by-product silage without additives was 70.94% in the present study. These discrepancies could be due to different artichoke plant varieties used in the experiments. The IVDMD values in various studies involving vegetable residues were 61.00% in sugar beet pulp

Table 2. *In vitro* dry matter digestibility (IVDMD) and energy values of silages, DM%

Parameters	Groups					*P*-value
	C	B1	B2	M1	M2	
IVDMD, % DM	$70.94^{c} \pm 1.07$	$79.47^{ab} \pm 2.28$	$77.51^{b} \pm 1.89$	$84.58^{a} \pm 1.92$	$83.80^{a} \pm 1.70$	<0.01
ME*, MJ/kg DM	$10.74^{c} \pm 0.16$	$12.03^{ab} \pm 0.35$	$11.74^{b} \pm 0.29$	$12.80^{a} \pm 0.29$	$12.69^{a} \pm 0.26$	<0.01
NE_L*, MJ/kg DM	$6.78^{c} \pm 0.11$	$7.65^{ab} \pm 0.23$	$7.45^{b} \pm 0.19$	$8.17^{a} \pm 0.20$	$8.10^{a} \pm 0.18$	<0.01

C – control, B1 – 2.5% crushed barley grain, B2 – 5% crushed barley grain, M1 – 2.5% sugar beet molasses, M2 – 5% sugar beet molasses; DM – dry matter, ME – metabolic energy, NE_L – net energy lactation; * formulas for: "digestible energy (DE), Mcal/kg DM = 0.04409 × %TDN" and "ME, Mcal/kg DM = 0.82 × DE" and "NE_L, Mcal/kg DM = 0.5557 × DE − 0.12" were used and converted to "Mega Joule" unit; data are presented as mean value ± SEM (standard error of the mean); [abc] – means within a row with different superscripts are significantly different at $P < 0.05$

silage (Sahin et al., 1999), 83.95% in sugar beet leaf silage (Can et al., 2003), and 82.2% in broccoli by-product silage (Monllor et al., 2020); in addition, the IVOMS values of tomato grass and potato pulp silages were reported at 51.51% and 77.29%, respectively (Tekin and Kara, 2020; Senyuz and Karsli, 2021).

The addition of barley and especially molasses to the artichoke residue (in parallel with the increase in IVDMD) resulted in significantly higher ME and NE_L values ($P < 0.05$) (Table 2). Konca et al. (2005) reported that the ME value of plain artichoke silage was 9.67 MJ/kg, and the NE_L value was 5.97 MJ/kg. The ME and NE_L values of plain artichoke silage were calculated in the current study to be 10.74 and 6.78 MJ/kg, respectively (based on IVDMD), and significant increases were achieved in these parameters by adding barley and especially molasses to the silage material. While ME values were in the range of 11.74–12.80 MJ/kg, the NE_L values varied from 7.45 to 8.10 MJ/kg. For different silage samples, Senyuz and Karsli (2021) calculated the ME and NEL values of maize silage as 10.71 and 5.44 MJ/kg, while corresponding values for potato pulp silage were 14.27 and 7.41 MJ/kg, respectively. Moreover, Tekin and Kara (2020) calculated the ME value for tomato herbage silage at 5.49 MJ/kg. Based on the energy values, by adding barley or molasses to artichoke residues, a silage with a similar or even higher energy value to maize silage can be obtained.

Fermentation parameters

After examining the fermentation parameters, it was found that although both silage additives numerically reduced the ammonia-N values, this decrease was significant only for molasses addition ($P < 0.05$) (Table 3). In other studies conducted with various silages, Sahin et al. (1999) reported the ammonia-N content at 0.87% in sugar beet pulp silage, while Senyuz and Karsli (2021) obtained a value of 0.46% in potato pulp silage. It should be noted that Limin Kung et al. (2018) emphasized a significant downward trend in the ammonia-N content due to the addition of carbohydrate source to the silage material, or a decrease in the amount of protein in the total silage material caused by increasing additive doses, and possible alterations in lactic acid metabolism. In the presented study, it was noticed that with increasing doses of barley (containing starch) and molasses (containing sucrose + glucose + fructose) additives, the total protein content and the amount of ammonia-N in the silages was gradually decreasing, which supported the above explanations.

Table 3. Silage fermentation parameters

Parameters	Groups					*P*-value
	C	B1	B2	M1	M2	
pH	$4.11^{a} \pm 0.03$	$3.73^{c} \pm 0.03$	$3.68^{c} \pm 0.01$	$3.75^{bc} \pm 0.05$	$3.85^{b} \pm 0.04$	<0.01
Ammonia-N, %	$0.90^{a} \pm 0.03$	$0.85^{a} \pm 0.02$	$0.82^{ab} \pm 0.06$	$0.73^{bc} \pm 0.02$	$0.66^{c} \pm 0.00$	<0.01
Flieg score*	$70.57^{c} \pm 1.44$ medium	$86.75^{b} \pm 1.29$ very good	$92.84^{a} \pm 1.19$ very good	$88.03^{ab} \pm 1.09$ very good	$89.20^{ab} \pm 4.20$ very good	<0.01
% as in silage DM						
lactic acid	$1.76^{d} \pm 0.10$	$3.34^{b} \pm 0.16$	$4.01^{a} \pm 0.30$	$2.27^{c} \pm 0.06$	$3.02^{b} \pm 0.05$	<0.01
acetic acid	$0.08^{c} \pm 0.01$	$0.11^{b} \pm 0.01$	$0.11^{b} \pm 0.01$	$0.14^{a} \pm 0.01$	$0.14^{a} \pm 0.01$	<0.01
propionic acid	0.001 ± 0.00	0.003 ± 0.01	0.001 ± 0.00	0.002 ± 0.00	0.001 ± 0.00	0.16
butyric acid	–	–	–	–	–	–

C – control, B1 – 2.5% crushed barley grain, B2 – 5% crushed barley grain, M1 – 2.5% sugar beet molasses, M2 – 5% sugar beet molasses; DM – dry matter; * calculated based on DM and pH values using the formula: "Flieg score = 220 + (2 × DM, %) − 15) − 40 × pH" (quality classification by score: 0–20 → poor, 21–40 → low, 41–60 → medium, 61–80 → good, 81–100 → very good); data are presented as mean value ± SEM (standard error of the mean); [a–d] – means within a row with different superscripts are significantly different at $P < 0.05$

Silage pH is one of the parameters that play an important role in determining the silage quality and should be in the range of 3.7–4.7 for an ideal silage fermentation process (Limin Kung et al., 2018). In previous studies on silages from artichoke by-products, the pH value was determined to be between 3.55 and 4.30 (Megias et al., 1997; Gul et al., 2001; Meneses et al., 2007; Monllor et al., 2020). In the present study, the addition of barley to the silage material caused a significant decrease in silage pH (3.68–3.73), while the highest value was obtained in the control group (pH 4.11) (Table 3). It was also observed that the addition of molasses to the silage material produced the same pH lowering effects (3.75–3.85). Nevertheless, silage pH ranged from 3.68 to 4.11, which was within the range of an ideal silage fermentation process. The pH values in the current study were significantly reduced after the addition of molasses and ground barley to the plain silage material. Similarly, Gul et al. (2001) also reported that the pH of silages was reduced following the addition of molasses (2%) or ground wheat (5%) to the artichoke residue silage material (to 3.48 and 3.44, respectively). It was possible that this downward trend was due to the fact that molasses, wheat or barley were rich in easily fermentable carbohydrates.

The lowest Flieg score was obtained in the present study in the additive-free silage group (70.57%), and a "medium" quality silage formed from this material (Table 3). On the other hand, when molasses and barley were added to the silage, the scoring increased significantly (86.75–92.84%) and silage material of "very good" quality was produced. This indicated that lower pH could be obtained by adding additives containing easily fermentable carbohydrates to the silage material, resulting in improved silage quality. Gul et al. (2001) and Can et al. (2003) also reported that similarly high Flieg scores were achieved when molasses and wheat were added to plain silage materials.

While lactic acid was the predominant organic acid observed in all experimental silage samples, propionic acid remained at very low levels (0.001–0.003%), and butyric acid was not present at all (Table 3). The literature review has shown that studies involving artichoke silage are quite limited; however, it was reported that butyric acids did not form during the fermentation process in artichoke silages (Gul et al., 2001). Likewise, it has been argued that propionic acid should not be present in a good quality silage or can only be found in very low (< 0.1%) amounts (Limin Kung et al., 2018). The data obtained in the presented study also confirmed the results published in the literature on the subject (Table 3). The highest lactic acid content was obtained in silages with barley (3.34–4.01%), and it was also significantly higher in silages with molasses (2.27–3.02%) compared to the control group (1.76%). With respect to acetic acid, the percentages were 0.14%, 0.11%, and 0.08% for groups M, B and C, respectively (Table 3). This indicated that the process of homofermentation occurred in all the silages obtained in the study, and that easily digestible carbohydrate sources added to the silage materials positively contributed to this process. Gul et al. (2001) reported that lactic acid proportion in artichoke by-product silages without additives, with 2% molasses and 5% wheat flake were 2.70%, 2.65% and 2.83%, respectively, while these values for acetic acid were 0.89%, 0.53% and 0.43%, respectively. In contrast, butyric acid levels were almost non-existent or completely absent in the silage material (Table 3). In another work, Meneses et al. (2005) reported that the lactic acid content was 1.98%, and total volatile fatty acids content was 1.46% in the artichoke by-product silage. Studies have also reported that lactic acid concentrations in ideal forage silages should be in the range of 2–4%, but this value was shown to increase above 6% in silage material with a low (< 35%) DM content (Limin Kung et al., 2018). In the presented study, ideal lactic acid values in silages were obtained, even though the DM content of the silage material was significantly low.

Conclusions

It can be concluded that the artichoke residue (leaves and stems) remaining after flower harvesting can readily be used in ruminant feeding for silage production. However, attention should be drawn primarily to the DM values of the feed materials, which are quite low at this stage of harvest. Therefore, it has been observed that very high-quality silage can be obtained by adding substances to the artichoke residue that increase the dry matter content of the silage.

Conflict of interest

The Authors declare that there is no conflict of interest.

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