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CHARACTERIZATION AND IN VITRO EVALUATION OF CARROT PULP ENSILED WITH DIFFERENT DRY ROUGHAGES

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Abstract: This study investigated the nutrient content, the digestibility of organic matter (OMD), and the metabolic energy (ME) values of silages prepared from carrot pulp, a by-product of the food industry. Five different silages with five replicates were prepared by adding wheat straw (CP + WS), vetch/oat hay (CP + VOH), maize stalk straw (CP + CS), alfalfa hay (CP + AH), and barley straw (CP + BS) as 20% absorption material to 80% carrot pulp. The silages were opened after 60 days, and physical and chemical analyses were performed. The dry matter content was highest in the CP+BS silage. Crude protein content was highest in the CP+AH and CP+VOH groups. CP+AH silage had the highest ADF and NDF. The CP+AH and CP+VOH groups had high-quality relative feed values, while all groups had very good Flieg quality values. There were no differences between the groups for OMD and ME. To conclude, it was found that carrot pulp silage can be used as an alternative feed source in animal nutrition.

Keywords: Silage, Carrot pulp, In vitro, Alternative roughage

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1. Introduction

Agro-industrial by-products result from various physical, chemical and biological processes of animal or plant products that are not used as raw materials in the production chain (Rosas et al., 2016). These by-products have attracted considerable interest due to their potential use in animal feed. Due to their local availability and low prices, they are used as the main components of livestock rations in many developing countries (Mugerwa et al., 2012). In Türkiye today, there is an incredible biodiversity of products that have gone through the industrialisation process; these produce non-traditional wastes (by-products, residues) (Mirzaei-Aghsaghali and Maheri-Sis, 2008; Özdemir and Okumuş, 2022; Özdemir and Ülger, 2022) that can be incorporated into the diets of dairy and beef cattle in the region. Among the industrialised products, fruits, vegetables, roots, etc., are sold fresh, while others are processed into nectars, juices, jams, wines, and canned food. The nutritional value and nutritional management of the resulting agro-industrial wastes and by-products have been discussed, and some studies have been conducted on the level at which these non-conventional feed resources can be used in the feed of different animal species (Tekin, 2017; Başar and Atalay, 2020). Studies have shown that fruit and vegetable wastes can be used as an alternative feed source due to the inadequacy of our existing feed resources in rational terms (quantity-quality-price) (Günal et al., 2017; Ülger et al., 2018; Gharehbagh et al., 2020; Özdemir and Ülger, 2022; Ülger and Özdemir, 2023).

The carrot (*Daucus carota* L.) is one of the most popular root vegetables grown worldwide (Torronen et al., 1996). In addition to their roots, carrots can be commercially processed into nutrient-rich processed products such as juice, canned food, pickles, etc. In 2022, 788,578 tonnes of carrots were produced in Türkiye (TÜİK, 2022). Up to 50% of the raw material in carrot juice production becomes waste in the form of pulp (Nocolle et al., 2003). If these data are evaluated, a large amount of carrot pulp is generated annually as waste from fruit juice factories in our country. As fruit and vegetable pulp deteriorates rapidly due to its high water content, it can be used fresh, dried, or ensiled for use as animal feed.

Today, many fruit pulps are no longer used in the industrialisation process. Therefore, evaluating the chemical composition and feed value of these non-traditional by-products, such as carrot pulp, is necessary and should be used as a reference. For this purpose, the possibilities of ensiling carrot pulp and the nutrient values, organic matter digestibility, and metabolic energy values of the silages were investigated in the present study.

2. Materials and Methods

The carrot (*Daucus carota* L.), alfalfa hay (*Medicago sativa*), wheat straw (*Triticum*), vetch/oat hay (*Vicia* *sativa-Avena sativa* L.), barley straw (*Hordeum vulgare* L.) and corn stalk straw (*Z. mays*) used in the study were obtained from livestock farms in Eskisehir and brought to Eskisehir Osmangazi University, Faculty of Agriculture, Laboratory of Animal Science. Carrot pulp was obtained using a juicer (Mehtap Reyyan MSM-3). Dry roughages were cut into approximately 1.5-2.2 cm long pieces. The rumen fluid was obtained from male Simmental cattle with a live weight of 600-650 kg, which was fed with a fattening diet + wheat + barley straw from a slaughterhouse (Keskin Et Entegre Kombinası) in Eskisehir immediately after slaughter.

The dry matter (DM) contents of carrot pulp and dry roughages were determined (AOAC, 2006) and five silage groups were prepared in 1 kg glass jars in 5 replications. The silages were prepared by mixing 80% carrot pulp + 20% dry roughage, resulting in 30% DM in the silage. The treatment groups were as follows: carrot pulp+wheat straw silage (CP+WS), carrot pulp+vetch/oat hay silage (CP+VOH), carrot pulp+corn stalk-straw silage (CP+CS), carrot pulp+alfalfa hay silage (CP+AH) and carrot pulp+barley straw silage (CP+BS). After 60 days, the silages were opened and dried (AOAC, 2006). To determine the dry matter (DM) content of the silages, they were dried in an oven at 55 ^{0}C for 96 hours until they reached a constant weight. After determining the dry weight of the silages, the samples were ground and prepared for analysis. Subsequently, ash, crude protein, and ether extract (AOAC, 2006) and cell wall components (crude fiber (CF), acid detergent fiber (ADF) and neutral detergent fiber (NDF)). Van Soest et al. (1991) measured in the milled silage samples (1 mm particle size). Organic matter (OM) and nitrogen-free extract (NFE) values were calculated. Relative feed value (RFV, Rohvveder et al., 1978) and RFV grade, used to determine the feed quality of carrot pulp silages, were calculated from dry matter digestibility (DMD) and dry matter intake (DMI) data (Van Dyke and Anderson, 2000). Flieg quality score and grade were calculated according to Kılıç (1986). pH values were measured using an electronic pH meter (HANNA Instruments I-2211). Organic matter digestibility (OMD) and metabolic energy (ME) of the samples were determined using the ANKOM^{RF} gas production system according to the gas production method reported by Menke and Steingass (1988).

The data were analyzed in SPSS 17.0 package program. The Kolmogorov-Simirnov test was applied for the data's normality assumption, and the variances' homogeneity was evaluated with the Levene test. The data of the study were subjected to a one-way analysis of variance. Duncan test, one of the multiple comparison tests, was used.

3. Results

3.1. Characteristics of Carrot Pulp and Dry Roughages

The nutrient composition and cell wall components of the carrot pulp and dry roughages used in the study are given in Table 1. The OMD and ME values of carrot pulp were higher than the dry roughages used for ensiling (Table 2).

3.2. Characteristics of Carrot Pulp Silages

The nutrient composition and cell wall components of the carrot pulp silage groups are shown in Table 3. DM was higher in the CP+BS group than in the CP+AH group and in the CP+AH group than in the other groups (P<0.001).

Table 1. Nutrient composition and cell wall components of carrot pulp and dry forages (%)

Material	DM	Ash	CP	EE	OM[1]	NFE[2]	ADF	NDF	CF
Carrot pulp	93.16	5.59	5.26	0.60	87.57	72.58	19.52	19.32	9.13
Wheat straw	91.25	10.53	4.58	1.67	80.72	45.62	44.03	68.09	28.85
Vetch/oat hay	89.81	8.31	15.84	0.75	81.50	44.63	28.85	39.13	20.28
Corn stalk-straw	89.91	7.61	5.31	1.52	82.30	46.76	43.68	72.35	28.71
Alfalfa hay	91.05	11.74	17.9	1.31	79.31	35.92	32.01	39.22	24.18
Barley straw	91.98	7.54	4.58	1.26	84.44	52.08	37.76	67.32	26.52

DM= dry matter, CP= crude protein, EE= ether extract, OM= organic matter, NFE= nitrogen-free extract, ADF= acid detergent fiber, NDF= neutral detergent fiber, CF= crude fiber. [1]OM= %DM-%Ash, [2]NFE= %DM – (%CP + %EE + %CS + %Ash).

Table 2. Gas production (ml), organic matter digestibility (OMD, %), and metabolic energy (ME, MJ/kg DM) values of carrot pulp and dry roughages

Material	Hour 3	Hour 6	Hour 12	Hour 24	Hour 48	Hour 72	OMD	ME
Carrot pulp	49.53	100.04	185.51	241.12	266.38	257.64	60.66	9.71
Wheat straw	13.58	27.89	50.45	98.48	142.87	146.03	39.63	6.34
Vetch/oat hay	31.14	65.72	111.57	159.39	187.34	184.65	45.91	7.35
Corn stalk-straw	22.12	48.86	91.41	159.48	202.99	199.35	49.48	7.92
Alfalfa hay	21.46	54.14	90.23	121.20	136.81	130.71	37.58	6.10
Barley straw	19.69	52.02	90.42	138.55	166.75	163.83	42.53	6.81

OMD= organic matter digestibility, ME= metabolic energy

Table 3. Nutrient composition and cell wall components of carrot pulp silage groups (%)

Silage	DM	Ash	CP	EE	OM[1]	NFE[2]	ADF	NDF	CF
CP+WS	26.35[c]	9.51[b]	5.55 [c]	0.47[b]	83.07[c]	50.05[c]	40.69[a]	53.25[a]	27.01[a]
CP+VOH	25.97[c]	9.58[b]	9.25[a]	1.76[a]	82.10[d]	50.43[c]	29.80[c]	39.48[b]	20.50[c]
CP+CS	26.40[c]	7.76[c]	5.55[c]	0.37[b]	83.88[b]	54.20[a]	37.12[b]	48.26[a]	24.06[b]
CP+AH	27.16[b]	11.48[a]	9.50[a]	1.75[a]	79.09[e]	48.08[d]	28.29[c]	32.78[c]	19.57[c]
CP+BS	27.93[a]	7.71[c]	6.59[b]	1.64[b]	85.47[a]	51.73[b]	34.75[c]	51.42[a]	25.69[ab]
P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
SEM	0.167	0.465	0.650	0.142	0.711	0.659	1.002	1.718	0.649

CP+WS= carrot pulp+wheat straw silage, CP+VOH= carrot pulp+vetch/oat hay silage, CP+CS= carrot pulp+corn stalk-straw silage, CP+AH= carrot pulp+alfalfa hay silage, CP+BS= carrot pulp+barley straw silage, DM= dry matter, CP= crude protein, EE= ether extract, OM= organic matter, NFE= nitrogen-free extract, ADF= acid detergent fiber, NDF= neutral detergent fiber, CF= crude fiber. [1]OM= %DM-%Ash, [2]NFE= %DM – (%CP + %EE + %CS + %Ash), SEM= standard error of the mean, a,b= within a row, means with different superscripts differ significantly (P<0.05).

Table 4. Dry matter digestibility (DMD, %), dry matter intake (DMI, %), relative feed values (RFV, %), pH and Flieg quality score values of carrot pulp silage groups

Silage	DMD	DMI	RFV	RFV grade	pH	Flieg quality score	Flieg quality score grade
CP+WS	57.30[e]	2.27[c]	100.77[d]	3rd quality	4.2	89.77	Very good
CP+VOH	65.39[b]	3.04[b]	154.15[b]	High	4.2	87.02	Very good
CP+CS	59.85[d]	2.49[c]	115.74[c]	2nd quality	4.2	89.08	Very good
CP+AH	67.36[a]	3.67[a]	191.66[a]	High	4.3	86.04	Very good
CP+BS	61.80[c]	2.38[c]	113.97[c]	2nd quality	4.2	91.01	Very good
P	<0.001	<0.001	<0.001		0.835	0.401	
SEM	0.555	0.081	5.147		0.036	1.545	

Silage group descriptions are the same as Table 4, [1] RFV grade value, [2] Flieg quality score grade value, SEM= standard error of the mean; a,b: Within a row, means with different superscripts differ significantly (P<0.05).

Table 5. Gas production (ml), organic matter digestibility (OMD, %), and metabolic energy (ME, MJ/kg DM) values of carrot pulp silage groups

Silage	Hour 3	Hour 6	Hour 12	Hour 24	Hour 48	Hour 72	OMD	ME
CP+WS	24.06	47.64	81.43	129.31	184.73	201.99	49.74	7.61
CP+VOH	26.82	77.30	136.56	168.75	197.28	205.08	50.40	7.72
CP+CS	26.25	50.08	95.05	156.31	211.98	232.16	55.11	8.41
CP+AH	38.08	84.41	138.51	168.58	190.17	193.57	48.52	7.43
CP+BS	34.82	68.41	116.48	166.99	213.82	225.84	53.75	8.21
P	0.690	0.280	0.090	0.420	0.740	0.270	0.279	0.298
SEM	3.244	6.412	8.696	7.229	7.254	6.432	1.093	0.164

Silage group descriptions are the same as Table 4, SEM= standard error of the mean, a,b: Within a row, means with different superscripts differ significantly (P<0.05).

The CP+AH silage had a higher ash content than the CP+WS and CP+VOH silages, and the CP+WS and CP+VOH silages had a higher ash content than the CP+CS and CP+BS silages (P<0.001). The highest crude protein values were obtained when alfalfa and vetch-oat hay were added as adsorbents to carrot pulp, followed by barley and wheat/corn stalk grass (P<0.001). EE was higher in CP+AH and CP+VOH silages than in the other silages (P<0.001). The organic matter content in the silage groups was higher in the CP+BS, CP+CS, CP+WS, CP+VOH and CP+AH groups (P<0.001). NFE was higher in the CP+CS group than in all groups, in the CP+BS group than in the CP+VOH, CP+AH and CP+WS groups, and in the CP+VOH and CP+WS groups than in the CP+AH group (P<0.001).

As shown in Table 3, the effect of treatments on cell wall components was significant (P<0.001). The ADF value was highest in the CP+WS silage and higher in the CP+CS silage than in the other groups. The NDF values were higher in the CP+WS, CP+CS and CP+BS silages than in the CP+VOH and CP+AH silages (P<0.001). The lowest CC content was found in CP+VOH and CP+AH silages, followed by CP+CS and CP+BS and CP+WS silages, respectively (P<0.001). According to Table 4, as a result of the calculation using DMD and DMI values, the highest RFV was found in CP+AH silage, followed by CP+VOH, CP+CS/CP+BS and CP+WS groups, respectively (P<0.001). There was no significant effect of treatments on pH and Flieg quality scores (P>0.05; Table 4). The factors had no effect on OMD, ME and gas production (P>0.05; Table 5).

4. Discussion

4.1. Characteristics of Carrot Pulp and Dry Roughages

All forages can be ensiled, but their suitability for ensiling varies with their dry matter and carbohydrate content (Yitbarek and Tamir, 2004; Büyükkılıç et al., 2018). Absorbents (absorption enhancers) are among the feed additives that are effective in silage preservation. In fact, the sugar (61.3%; Ramos-Andrés et al., 2020) and moisture (84.67%) contents of carrot pulp are high. For this reason, it can be ensiled with absorbent additives and used as an alternative feed material in animal nutrition. The dry matter content of dry roughage used as an absorbent in the current study showed a value between 89.91-91.98% and was compatible with the literature. Similarly, the nutrient composition of the carrot pulp and dry roughage used in the current study was consistent with the literature (Jagtap et al., 2000; Wadhwa et al., 2015; Ergün et al., 2020).

When fibre content, OMD, and ME values of all silage materials used in the present study are considered, carrot pulp had much lower fibre and higher OMD and ME values than dry roughages used as absorbents. This situation allows carrot pulp to be supplemented with dry roughages for silage production. Indeed, Azizi et al. (2019) compared the chemical composition and nutritional value of carrot pulp with wheat straw and alfalfa and observed the highest and lowest gas production volume and constant gas production rate after 16 and 24 h of incubation in carrot pulp and wheat straw incubation, respectively. However, the highest gas production volume and gas production potential were observed for alfalfa, while the lowest amount was observed for wheat straw. The positive correlation between organic matter digestibility and the ME value of a feed explains why the ME value of carrot pulp was higher than that of dry roughages in the study. Since this situation gives information about the nutritional value of feeds, the nutritive value of carrot pulp will be high.

4.2. Characteristics of Carrot Pulp Silages

Depending on the chemical composition of the nutrients in the forages, there may be differences in their nutritional value, and these differences may be reflected in the quality of the silages. Indeed, in the present study, the different roughages added to the carrot pulp reflected the differences in their chemical composition in the silages.

The DM content, an important indicator of silage quality, indicates the amount of nutrients available to the animal in the silage. The DM content varies according to the raw materials used in fruit and vegetable pulp silages. Santos et al. (2014) reported 33.7% DM in grape pulp silages, and Başar and Atalay (2020) reported 6.76-9.66% DM in different citrus pulp silages. Considering that the DM content of the highest quality corn silages is between 25-32% (Kılıç, 1986), all silages obtained in the present study can be considered as good quality in terms of DM content (25.97-27.93%). This situation shows that the ensiling potential of carrot pulp is high.

The ash content, which is a measure of the ability to meet the mineral requirements of animals, was higher in carrot pulp silages (7.71-11.48%) than in corn silage (4.81%) (Tharangani et al., 2021) and citrus silage (3.26-5.33%) (Başar and Atalay, 2020). This may be due to the different mineral contents of dry roughage as absorbents for silages. In fact, the carrot pulp silage to which the highest ash content alfalfa hay was added had the highest ash content. Similarly, the differences between the groups in terms of protein content showed that the raw materials used were linearly influenced by the protein content. The CP+AH and CP+VOH silages contained 9.50% and 9.25% protein respectively, while the other silage groups gave values close to corn silage. In the studies carried out with different fruit pulps, the protein ratio showed a wide range. Özdemir and Ülger (2022) reported protein values of 6.20-7.80% in peach pulp, Başar and Atalay (2020) reported 6.50-11.46% in different citrus pulps and Massaro Junior et al. (2022) reported 13.98% in grape pulp. The use of different absorbent materials, as well as different varieties and species, can accentuate this difference. Indeed, legume grasses, which are difficult to ensilage due to their high crude protein content, low concentration of water-soluble carbohydrates and high buffering capacity, are prone to proteolysis (Muck, 2010). Therefore, the addition of high-protein forages to carrot pulp with a high water-soluble carbohydrate content resulted in successful ensiling and increased protein content of silage. The amount of protein in a feed is the most important indicator of feed quality (Gillen and Berg, 1998). As the digestibility of roughage increases with the protein content of the feed, ruminant diets should contain at least 7-8% crude protein on a dry matter basis for healthy microbial activity (Van Soest, 1994). Therefore, it can be said that carrot pulp silages with alfalfa hay and vetch-oat hay are high quality diets. When the silage groups were analysed for EE content, despite the differences, the EE content (0.37-1.76%) was lower than that of corn silage, which may be because both carrot pulp (0.6%) and absorbent additives had low EE content (0.74-1.67%).

The highest OM content was in the CP+BS silages (85.47%). In comparison, the lowest value was found in the CP+AH group (79.09%). The reason for the lower OM content compared to corn silage is the high ash content of the silage materials used in this study. The amount of NFE calculated to determine the content of easily soluble carbohydrates was found to be the lowest in CP+AH silage, although there was a difference between the groups (48.08-54.20%) compared to corn silage (59%) (Sarıçiçek et al., 2016). This is because the crude protein content is higher in CP+AH silage than in corn silage and other carrot pulp silages.

ADF and NDF content negatively correlate with feed digestibility and intake capacity, respectively. Roughages with high NDF content reduce feed intake in high yielding dairy cows. Indeed, in the present study, the NDF, ADF, and fiber contents of carrot pulp silages made by adding vetch-oat and alfalfa hay were found to be at the desired levels in the diet of dairy cows. The ADF content was higher, especially in the groups containing straw. The higher ADF content of roughage, such as straw, can explain this. There is a positive relationship between the NDF content and the water-holding capacity of a feed (Razak et al., 2012). This suggests that the dry roughage used as an absorbent in the current study may be a potential supplement. In addition, it has been reported that NDF reduces the in vitro digestibility and, thus the dry matter content of diets with a high NDF content (Mahyuddin, 2008; Mertens et al., 2012). The fact that the dry roughage used in this study did not reduce digestibility indicates that ensiling was successful.

Relative feed value (RFV) is widely used as an index to assess quality and compare feed types and prices. Higher RFVs indicate higher feed quality (Jeranyama and Garcia, 2004). The protein content of the feed is not taken into account when calculating the RFV, but higher RFV values are generally associated with higher protein content (Stallings, 2006). Indeed, the present results confirm this information. The CP+AH and CP+VOH groups, which had lower ADF and NDF contents, had the highest RFV values, while their protein contents were higher than the other groups. In view of this information, it can be said that the silages obtained by adding alfalfa and vetch-oat hay to carrot pulp have a high feed quality.

One of the most important factors influencing fermentation during ensiling is pH. Good silage should have a pH of 3.8-4.2. Although there was no difference between silage pH values in the present study, it can be said that the pH values of all silages except the CP+AH group were within the accepted limits for good silages (Ergün et al., 2020). Similarly, there was no difference between groups in the Flieg quality scores used to determine silage quality, but all our groups were considered very good quality (85-100).

The nutritional value of a ruminant feed is determined by the concentration of chemical constituents and the rate and extent of their digestion. It is very important to determine not only the nutrient content and quality but also the digestibility of the feed (Ayaşan et al., 2020). In our silages obtained in the study, OMD was found between 93.65-52.50%, while ME values were found between 6.94-8.02 MJ/kg DM, and there was no statistical difference between the groups. The effect of the factors on gas production was also found to be insignificant. When the data obtained were compared with the OMD values of adsorbent feeds used in the preparation of carrot pulp silage, it was found that the addition of adsorbent to carrot pulp did not affect ensiling; on the contrary, OMD digestibility increased (Table 6). The differences in nutrient composition, cell wall components, and NDF between groups were not reflected in OMD, ME, and gas production. Studies report that dietary NDF and HP are both negatively and positively associated with gas production (Ndlovu and Nherera, 1997; Larbi et al., 1998). Several factors influence the fermentation of feed by rumen microorganisms and, thus, gas production. Therefore, the lack of difference in our in vitro digestibility results in this study may be due to feed components such as EE and protein that contribute little or no gas production but are degraded in vitro.

Table 6. Effect of adding carrot pulp to adsorbents on OMD (%)

Material	OMD
CP+WS	49.74
Wheat straw	39.63
CP+VOH	50.4
Vetch/oat hay	45.91
CP+CS	55.11
Corn stalk-straw	49.48
CP+AH	48.52
Alfalfa hay	37.58
CP+BS	53.75
Barley straw	42.53

CP+WS= carrot pulp+wheat straw silage, CP+VOH= carrot pulp+vetch/oat hay silage, CP+CS= carrot pulp+corn stalk-straw silage, CP+AH= carrot pulp+alfalfa hay silage, CP+BS= carrot pulp+barley straw silage.

5. Conclusion

In general, the wide variation in the chemical composition of different feeds offers users flexibility in formulating rations according to the productive performance of the target animals. Considering the properties studied for this purpose, carrot pulp, like other agro-industrial by-products, has the potential to be ensiled and used as animal feed.

Author Contributions

The percentage of the author(s) contributions is presented below. All authors reviewed and approved the final version of the manuscript.

	A.F.K.	C.K.B.
C		100
D		100
S		100
DCP	90	10
DAI	90	10
L	60	40
W	50	50
CR		100
SR		100
PM		100
FA		100

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because there was no study on animals or humans.

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