Journal of Elementology ISSN 1644-2296

Borsuk M., Purwin C., Baranowska M., Antoszkiewicz Z., Nogalski Z., Mazur-Kuśnirek M. 2021.
Assessment of the nutritional value of Sida hermaphrodita (L.) Rusby *(Virginia fanpetals): chemical composition of herbage and silage.*
J. Elem., 26(1): 249-260. DOI: 10.5601/jelem.2021.26.1.2075

RECEIVED: 6 November 2020
ACCEPTED: 6 February 2021

ORIGINAL PAPER

ASSESSMENT OF THE NUTRITIONAL VALUE OF *SIDA HERMAPHRODITA* (L.) RUSBY (VIRGINIA FANPETALS): CHEMICAL COMPOSITION OF HERBAGE AND SILAGE*

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Abstract

Sida hermaphrodita as a crop plant could be used as raw material for the production of forage. The aim of this study was to evaluate the overall nutritional value of fresh and ensiled biomass of *Sida hermaphrodita*, harvested in the bud formation stage. The chemical and amino acid composition, fatty acid profile, concentrations of minerals and polyphenols of herbage and silage were determined. Additionally fermentation products were assessed in silage. Herbage contained crude protein (CP) of 182 g kg^{-1} dry matter (DM), neutral detergent fiber (NDF) of 375 g kg^{-1} DM and lignin content in NDF (L/NDF) was 8.88. Nitrogen fractions changed as a result of ensiling (P<0.010), non-protein nitrogen (NPN) from 274 g kg^{-1} total nitrogen (TN) in herbage to 683 g kg^{-1} TN in silage, and neutral detergent-insoluble nitrogen (NDIN) from 74.6 g kg^{-1} TN in herbage to 79.5 g kg^{-1} TN in silage. Silage was characterized by intensive lactic fermentation (114 g kg^{-1} DM) and pH of 4.30. It contained CP of 176 g kg^{-1} DM, NDF of 378 g kg^{-1} DM, and L/NDF (11.3) was higher than in the herbage. The CP of *Sida hermaphrodita* silage had a high content of essential amino acids (AAs) Lys, Thr, Val, Leu and Phe (3.98, 4.19, 4.55, 7.14 and 4.00 g 100 g^{-1} CP, respectively). *Sida hermaphrodita* silage was characterized by the highest K (6.262 g kg^{-1}DM) content among macronutrients, and the highest content of Fe (40.88 mg kg^{-1} DM) and Mn (33.01 mg kg^{-1} DM) among micronutrients. Polyunsaturated fatty acids (PUFAs) predominated in the ether extract herbage and silage, and their proportion was three-fold and seven-fold higher than the proportion of monounsaturated fatty acids (MUFAs), respectively. Herbage had high quercetin content (652 μg g^{-1} DM), which decreased by 45% during the ensil-

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* This study was supported by the National Center for Research and Development as part of a research project entitled "Dietary, power and economic potential of *Sida hermaphrodita* cultivation on fallow land" under the "Natural Environment, Agriculture and Forestry" – BIOSTRATEG program (grant No. 1/270745/2/NCBR/2015).

ing. Changes in the chemical composition suggest that this crop plant can be preserved by ensiling. The results of this study indicate that *Sida hermaphrodita* can be used for producing high-quality silage for ruminants.

Keywords: *Sida hermaphrodita,* Virginia fanpetals, herbage, silage, chemical composition, nutritional value, polyphenols, amino acids composition.

INTRODUCTION

Sida hermaphrodita (L.) Rusby (Virginia fanpetals) is a perennial crop that is native to North America. The species has a productive life of up to 20 years, and its yields range from 9 to 20 t ha^{-1} DM, depending on the harvest date. The production of *Sida hermaphrodita* minimizes soil erosion and improves soil structure and fertility. *Sida hermaphrodita* delivers ecological benefits by storing carbon in its extensive root system and sequestering this element in agricultural soil for many years. It is characterized by moderate resistance to pests and diseases, considerable winter hardiness (to -35°C), resistance to drought, and low soil requirements. In comparison with other energy crops, *Sida hermaphrodita* is easy to cultivate and harvest. It is a source of nectar for pollinating insects, and it can be used in the phytoremediation of contaminated soils and in the production of textiles and herbal preparations (Borkowska, Molas 2012, 2013, Nahm, Morhart 2018).

In recent years, *Sida hermaphrodita* has attracted the interest of European producers as an environmentally-friendly source of biomass (Nahm, Morhart 2018). *Sida hermaphrodita* grows rapidly and its green biomass can be harvested twice per year. The first-harvest herbage is characterized by a more beneficial leaf-to-stem ratio, higher CP content and lower crude fiber (CF) content. First-cut green biomass can be used as fodder for livestock and second-cut biomass harvested at the end of the growing season can be effectively used for energy production purposes. Previous research has demonstrated considerable variations in the chemical composition of *Sida hermaphrodita* biomass harvested on different dates (Tarkowski 2003, Borkowska, Molas 2012, 2013). According to Tarkowski (2003), first-cut herbage used as fodder should be optimally harvested in the bud formation stage.

The nutritional value of *Sida hermaphrodita* has not been comprehensively analyzed in recent reviews of alternative and novel feeds for ruminants (Halmemies-Beauchet-Filleau et al. 2018). The ensiling suitability of *Sida hermaphrodita* has been investigated by Fijałkowska et al. (2017), who found that *Sida hermaphrodita* silage without additives is characterized by extensive lactic acid fermentation with low concentrations of VFAs. Antoszkiewicz et al. (2019) studied the effect of the harvest date and cutting height on the concentrations of carotenoids and tocopherols in *Sida hermaphrodita* herbage and silage.

The aim of this study was to evaluate the overall nutritional value of fresh and ensiled biomass of *Sida hermaphrodita*, harvested in the bud formation stage.

Hypothesis: *Sida hermaphrodita* may be an alternative plant material for silage with a chemical composition indicating high nutritional value.

MATERIALS AND METHODS

Sida hermaphrodita herbage and ensiling

The study was conducted in 2015, in north-eastern Poland (53°05′27.7″N, 21°11′47.5″E). The plantation was established in 2010, in Pienice, on soil classified as representing class IV of the rye complex. The plant density was 6 plants m^2. In the year of the study, the mean annual temperature was 8.5°C, and the annual total precipitation was 500 mm. At the beginning of the growing season, plants were fertilized with 100 kg nitrogen (N) ha^{-1}, 50 kg potassium oxide (K_2O) ha^{-1} and 80 kg phosphorus (V) oxide (P_2O_5) ha^{-1}. The *Sida hermaphrodita* plantation was divided into 3 plots (10 x 100 m), which served as replicates. The experimental material was first-cut herbage of *Sida hermaphrodita* harvested in the bud formation stage (11 June), cut at a height of 25 cm and collected with a Claas Jaguar 930 self-propelled forage harvester equipped with a Kemper 360 (GmbH, Harsewinkel, Germany) attachment. During harvest, the biomass was cut into 10-mm-long pieces. Three forage samples were collected from each plot before ensiling. Fresh *Sida hermaphrodita* biomass (224 g kg^{-1} DM) was ensiled in 220 L standard open-head high-density polyethylene (HDPE) drums (Brenntag GmbH, Essen, Germany) without drainage holes, and it was compressed to the density of 830 kg fresh matter (FM) m^{-3} without additives. The silage was prepared in three replications. After 90 days, silage samples were collected with a probe (ϕ 80 mm) along the entire length of the drums. Some samples were dried at 60°C for 48 h in the Binder FED 115 dryer, and ground in a Retsch SK 100 mill to a 1 mm particle size. The remaining samples were frozen at -25°C.

Chemical analyses

Chemical composition

Samples of plant material and silage were assayed for proximate chemical composition according to the procedures described by Purwin et al. (2015), water-soluble carbohydrates (WSC) – by the anthrone method (Thomas 1977), NDF assayed with heat-stable amylase and expressed exclusive of residual ash, acid detergent fiber (ADF) expressed exclusive of residual ash and acid detergent lignin (ADL) – according to Van Soest et al. (1991) using

an ANKOM220 fiber analyzer (ANKOM Technology Corp., Macedon, NY, USA). The DM content in herbage and silage samples was determined by the oven method at 60°C according the method cited by Purwin et al. (2015). DM content in silage samples was corrected using the equation proposed by Porter and Murray (2001) for drying at 60°C.

Fermentation products and fatty acid profile

The content of ammonia nitrogen (N-NH_3) in silage was determined by direct distillation using a 2100 Kjeltec Distillation unit (FOSS Analytical A/S, Hilleröd, Denmark) after increasing the pH of the samples by adding MgO; acidity was measured with an HI 8314 pH meter (Hanna Instruments, Woonsocket, RI, USA). The concentrations of lactic acid and fatty acids were determined as described by Kostulak-Zielińska and Potkański (2001) and Gąsior (2002).

Fatty acids were separated and determined by gas chromatography on a Varian 450 gas chromatograph with a Varian CP-8410 autosampler, flame-ionization detector (FID), CP-FFAP capillary column (length – 25 m, inner diameter – 0.53 mm, film thickness – 1.0 µm), sample size - 1 µl, detector temp. – 260°C, injector temp. – 200°C, column temp. – 90°C to 200°C, carrier gas - helium (flow rate 5.0 ml min^{-1}). Lactic acid content was determined by high performance liquid chromatography (HPLC, Shimadzu, Kyoto, Japan) with isocratic flow. Separation was carried out using a Varian Metacarb 67H column (Organic Acids Column), mobile phase: 0.002 M solution of sulfuric acid in deionized water, flow rate of 1 cm^3 min^{-1}, UV detector, 210 nm. External fatty acid standards were supplied by SUPELCO, and the lactic acid standard – by FLUKA.

Protein composition

Non-protein nitrogen (NPN) was calculated as a difference between total nitrogen and protein nitrogen determined with the use of trichloroacetic acid (TCA), and acid detergent insoluble nitrogen (ADIN) and neutral detergent insoluble nitrogen (NDIN) were determined based on the method proposed by Licitra et al. (1996). Amino acid nitrogen was measured as total free amino acids determined as described by Purwin et al. (2014).

Macronutrients and micronutrients

In order to analyze macronutrients and micronutrients in herbage and silage, the samples were wet mineralized with a mixture of hydrochloric acid and nitric acid (V) (3:1), in a MarsXpress microwave oven (1 h). The temperature was steadily increased to 170°C. The mineralizate was transferred to volumetric flasks (50 cm^3), and deionized water was added. Blank (reagent) samples were prepared simultaneously. The content of Cu, Mn, Fe, Zn, Ca, Mg, Na and K was determined by flame atomic absorption spectro-

metry (acetylene-air flame) on the Varian AA240FS (Varian, Palo Alto, California, USA) fast sequential atomic absorption spectrometer, fitted with an acetylene-air burner and cathode lamps. The minerals were determined at the following wavelengths (nm): Cu – 324.8, Mn – 279.5, Fe – 248.3, Zn – 213.8, Ca – 422.6, Mg – 285.2, Na – 586 and K – 766.5. The P content of mineralizates was determined by colorimetry, using an Epoll-30 ECO (Poll Ltd., Warsaw, Poland) spectrophotometer, at a wavelength of 405 nm. The solution was subjected to a color reaction with the molybdovanadate reagent.

Polyphenols

Selected polyphenols (ferulic acid, p-coumaric acid, vanillic acid, quercetin, isorhamnetin, catechin, apigenin and luteolin) were analyzed at the Institute of Animal Reproduction and Food Research of the Polish Academy of Sciences (Olsztyn, Poland) according to the methods proposed by Wiczkowski et al. (2016) and Jeż et al. (2018). Polyphenols in free form, released by alkaline hydrolysis, released by acid hydrolysis and total polyphenols were determined.

Calculations and statistical analyses

The results were presented as means and standard errors of the mean (SEM). The results were processed statistically by analysis of variance (one-way ANOVA). The ensiling process was an experimental factor. The significance of differences between mean values was determined by the Duncan's test. The results were analyzed statistically using Statistica v. 12.0.

RESULTS AND DISCUSSION

Chemical composition of herbage and silage

Ensiling decreased the content of DM (P=0.004) and WSC (P=0.008) – Table 1. *Sida hermaphrodita* silage evaluated in the current study had similar CP content and lower proportions of NDF and lignin (by 45 and 18 g kg^{-1} DM, respectively), compared with *Sida hermaphrodita* silage analyzed by Fijałkowska et al. (2017), where herbage was harvested in the same growth stage. The CP content of *Sida hermaphrodita* silage (Table 1) approximated that of alfalfa silage (180 g kg^{-1} DM) – Chrenkova et al. (2014). In this work, alfalfa silage contained NDF – 474 g kg^{-1} DM, ADF – 397 g kg^{-1} DM, and lignin – 99 g kg^{-1} DM, whereas the NDF content of *Sida hermaphrodita* silage was lower by 96 g kg^{-1} DM. The difference between the NDF and ADF fiber, which is indicative of the hemicellulose content, was lower in *Sida hermaphrodita* silage (64 g kg^{-1} DM on average) than in alfalfa silage (77 g kg^{-1} DM) – Chrenkova et al. (2014). The lignin content of *Sida herma-*

Table 1

Chemical composition, fermentation products (g kg^{-1} DM), concentration of N-NH_3 (g kg^{-1} TN) and pH of herbage and silage

Specification	Herbage (n=9)	Silage (n=9)	SEM	P value
Dry matter (g kg^{-1})	224	199	8.44	0.004
Crude ash (g kg^{-1} DM)	78.1	88.9	4.00	0.103
Crude protein (g kg^{-1} DM)	182	176	1.89	0.315
NDF (g kg^{-1} DM)	375	378	14.4	0.512
ADF (g kg^{-1} DM)	289	314	10.8	0.162
ADL (g kg^{-1} DM)	33.3	42.8	5.15	0.346
WSC (g kg^{-1} DM)	78.4	6.59	18.7	0.008
pH	-	4.30	1.05	-
N-NH_3 (g kg^{-1}TN)	-	100	0.93	-
NPN (g kg^{-1}TN)	274	683	93.7	<0.010
NDIN (g kg^{-1}TN)	74.62	79.5	1.64	<0.010
ADIN (g kg^{-1}TN)	65.0	63.0	3.03	0.211
Lactic acid (g kg^{-1} DM)	-	114	0.72	-
Acetic acid (g kg^{-1} DM)	-	19.5	0.91	-
Butyric acid (g kg^{-1} DM)	-	8.57	1.16	-

NDF – neutral detergent fiber, ADF – acid detergent fiber, ADL – acid detergent lignin, WSC – water-soluble carbohydrate, NPN – non-protein nitrogen, NDIN – neutral detergent--insoluble nitrogen, ADIN – acid detergent-insoluble crude nitrogen, SEM – standard error of the mean

phrodita was less than half that reported in alfalfa (Chrenkova et al. 2014) The L/NDF ratio of ensiled *Sida hermaphrodita* (11.3) testified to its high nutritional value. The above parameter was lower than that determined in alfalfa (18.6) and red clover (14.2) by Purwin et al. (2014), and lower than that determined in alfalfa silage (20.8) and grass clover silage (17.9) by Chrenkova et al. (2014). The above parameter was also lower in amaranth (6.4 in herbage, 6.7 in silage), which contained similar amounts of NDF, but significantly less lignin (28.7 g kg^{-1} DM in herbage, 29.2 g kg^{-1} DM in silage). The hemicellulose content of amaranth was higher by 94 g kg^{-1} DM (159 g kg^{-1} DM in herbage, 157 g kg^{-1} DM in silage) by Rezaei et al. (2009). *Sida hermaphrodita* silage had a desirable pH and a high concentration of lactic acid (80% of total acids). In the work of Purwin et al. (2009), the content of fermentation products in grass, alfalfa and maize silage was similar and indicative of very high quality. The lactic acid content of *Sida hermaphrodita* silage ranged from 80 to 120 g kg^{-1} DM. The butyric acid content of silage was indicative of the extent to which sugars and lactic acid were degraded by saccharolytic Clostridia (Purwin et al. 2009).

Protein composition

The result of ensilage was intensive proteolysis, hence NPN increased from 274 to 683 g kg^{-1} TN (P<0.010), which significantly reduced the quality of CP. The ensiling process contributed to an increase in the proportions of NDIN (P < 0.010), which is an indicator of the intensity of oxygen and thermal processes in silage. NPN in *Sida hermaphrodita* herbage (Table 1) was similar to that reported in the literature (10-25% CP) – Givens, Rulquin (2004) for grass, alfalfa and red clover forage by Purwin et al. (2014). The range of proteolysis in *Sida hermaphrodita* was similar or slightly lower than in alfalfa silage (NPN=44-87% TN) – Luchini et al. (1997), Kung, Muck (2006), but higher than in red clover silage (NPN=7-40% TN) – Papadopoulos, McKersie (1983). The content of ADIN in *Sida hermaphrodita* herbage and silage was similar to that reported in the fresh biomass of alfalfa (68.6 g kg^{1} TN) – Purwin et al. (2014). In further studies, Purwin et al. (2015) the content of NDIN during the ensilaging of alfalfa increased significantly (95.9 g kg^{-1} TN), remaining at a higher level than in the studied silage.

Ensiling also led to a significant increase in the concentrations of Asp (P=0.038), Ala (P=0.018) and Tyr (P<0.010), and a decrease in the concentrations of Glu (P=0.038), Phe (P=0.039), Lys (P=0.019), Cys (P=0.018)) and Arg (P<0.010) (Table 2). Ensiling decreased total AA content (P=0.044). *Sida*

Table 2

Amino acid profile (g 100 g^{-1} CP) of Virginia fanpetals herbage and silage

Amino acid	Herbage (n=9)	Silage (n=9)	SEM	P value
Asp	9.19	10.8	0.431	0.038
Thr	4.14	4.19	0.046	0.687
Ser	3.75	2.99	0.211	0.051
Glu	10.5	7.71	0.730	0.038
Pro	4.45	4.44	0.141	0.984
Gly	5.02	4.64	0.119	0.115
Ala	5.74	6.37	0.158	0.018
Val	4.61	4.55	0.053	0.650
Ile	3.55	3.72	0.068	0.259
Leu	7.25	7.14	0.116	0.695
Tyr	5.91	9.41	0.825	<0.010
Phe	4.51	4.00	0.136	0.039
His	2.91	2.34	0.225	0.240
Lys	4.91	3.98	0.236	0.019
Arg	4.00	1.44	0.575	<0.010
Cys	0.59	0.45	0.034	0.018
Met	1.17	1.15	0.013	0.672
Trp	1.20	0.95	0.078	0.096
Total	83.4	80.3	0.834	0.044

SEM – standard error of the mean

hermaphrodita forage in the study Tarkowski and Truchliński (2011) obtained a lower content of AAs: Met, Thr, His, Leu, Ile, Val, Phe and Tyr (0.81 vs. 1.96 vs. 1.67 vs. 3.47 vs. 2.27 vs. 2.92 vs. 3.14 vs. 1.21 g 100 g^{-1} CP), Lys content was similar (3.88 g 100 g^{-1} CP). Fermentation also induces changes in the composition of AAs through decarboxylation, deamination and Stickland reactions (Winters et al. 2001, Givens, Rulquin 2004). The total AA content of *Sida hermaphrodita* (Table 2) was similar to that of alfalfa and red clover (Purwin et al. 2014). Ensiling decreased the total AA content, both in the current study and in the work of Purwin et al. (2015). In the current research, changes in AA composition included a decrease in the concentrations of Arg and His, which corroborates the findings of Givens and Rulquin (2004). A decrease in the content of Arg and Glu during the ensiling process was also reported by Winters et al. (2001). The loss of Lys and Arg can be attributed to the fact that these AAs are metabolized by proteolytic Clostridium strains (Purwin et al. 2015).

Fatty acid profile

Ensiling induced changes in the fatty acid profile (Table 3). An increase in the total content of unsaturated fatty acids (UFAs, P=0.012) was accompanied by a decrease in the total MUFA content (P<0.010). The content of C18:1 decreased, and the content of C18:3 increased (P<0.010) during ensiling. *Sida hermaphrodita* herbage was characterized by considerably higher concentrations of fatty acids C12:0, C14:0, C16:0, C16:1, C18:0, C18:1, C18:2 and C18:3 than grasses in study by Boufaied et al. (2003). The greatest differences were reported in the content of C18:3, which was 66% lower in grasses (9.26 g kg^{-1} DM) than in *Sida hermaphrodita*. In the work of Boufaied et al. (2003), fatty acid concentrations were lower in alfalfa and grasses than in *Sida hermaphrodita*. The content of C18:3 ranged from 6.04 to 6.90 g kg^{-1} DM across the examined varieties. The fatty acid composition of silage is highly dependent on the fermentation process, and suboptimal fermentation decreases the amount of C18:3 in the substrate Van Rast et al. (2009). In the current study, the concentration of C18:3 increased in ensiled *Sida hermaphrodita*. In a study by Van Rast et al. (2009), the fatty acid profile of *Sida hermaphrodita* was characterized by higher concentrations of C16:0, C18:1 and C18:2, and a lower content of C18:3 relative to small-seeded legumes and ryegrass. In the cited study, the ensiling process increased the content of C16:0, whereas a reverse trend was noted in the current study.

Macronutrients and micronutrients

The ensiling process had no significant influence on the content of minerals in silage (Table 4). The losses of Zn and Na during ensiling were similar (56% and 53% respectively), and Mg was characterized by the lowest loss (11%). The Ca content of *Sida hermaphrodita* (Table 4) was low relative

Table 3

Fatty acid profile (g kg^{-1} DM) of Virginia fanpetals herbage and silage

Fatty acid	Herbage (n=9)	Silage (n=9)	SEM	P value
$C_{12:0}$	0.34	0.51	0.05	0.075
$C_{12:1}$	1.44	1.07	0.12	0.136
$C_{14:0}$	1.28	0.91	0.10	0.015
$C_{14:1}$	0.41	0.49	0.04	0.366
$C_{15:0}$	0.63	0.22	0.10	0.003
$C_{16:0}$	29.4	24.1	1.35	0.017
$C_{16:1}$	2.01	1.72	0.10	0.151
$C_{17:0}$	0.97	1.67	0.16	0.003
$C_{17:1}$	0.55	0.23	0.08	0.018
$C_{18:0}$	3.14	2.25	0.21	0.006
$C_{18:1}$	11.5	5.58	1.34	<0.010
$C_{18:2}$	20.5	21.7	0.60	0.376
$C_{18:3}$	27.8	39.6	2.66	<0.010
SFAs	35.8	29.6	1.52	0.012
MUFAs	15.9	9.10	1.55	<0.010
PUFAs	48.3	61.3	2.94	<0.010
UFAs	64.2	70.4	1.52	0.012
DFAs	67.3	72.6	1.32	0.015
OFAs	32.7	27.4	1.32	0.015

SFAs – saturated fatty acids, MUFAs – monounsaturated fatty acids, PUFAs – polyunsaturated fatty acids, UFAs – unsaturated fatty acids, UFAs = MUFAs + PUFAs, DFAs – hypocholesterolemic fatty acids, DFAs = UFAs + $C_{18:0}$, OFAs – hypercholesterolemic fatty acids, OFAs = SFAs – $C_{18:0}$, SEM – standard error of the mean

Table 4

Macronutrients (g kg^{-1} DM) and micronutrients (mg kg^{-1} DM) in Virginia fanpetals herbage and silage

Specification	Macronutrients					Micronutrients			
	Na	K	Mg	Ca	P	Fe	Cu	Zn	Mn
Herbage (n=9)	0.021	7.251	0.434	3.329	0.582	58.91	1.707	11.84	48.76
Silage (n=9)	0.010	6.262	0.387	2.025	0.542	40.88	1.159	5.272	33.01
SEM	0.004	0.365	0.026	0.455	0.028	10.72	0.194	3.080	7.538
P value	0.148	0.202	0.428	0.171	0.538	0.463	0.179	0.339	0.350

SEM – standard error of the mean

to that determined in fresh amaranth by REZAEI et al. (2009). The Ca:P ratio of *Sida hermaphrodita* decreased from 5.7:1 in herbage to 3.7:1 in silage, but it was still above the 2:1 threshold recommended for ruminants, which points to unbalanced sources of Ca and P. The concentration of K in *Sida hermaphrodita* was within the range recommended for ruminants (30 g kg^{-1} DM, NRC 2001). *Sida hermaphrodita* was far less abundant in macronutrients than amaranth (REZAEI et al. 2009). The content of macronutrients and micronutrients was very low in *Sida hermaphrodita* herbage and silage relative to whole alfalfa plants, where the average nutrient levels in the second cut cycle were determined at (in kg DM): N – 39 g, P – 3 g, K – 21 g, Ca – 21 g, Mg – 7 g, Fe – 194 mg, Zn – 24 mg, and Cu – 14.5 mg (MARKOVIĆ et al. 2009).

Polyphenols

The ensiling process led to a decrease in the total concentrations of polyphenols, in particular *p*-coumaric acid (by 98%) – Table 5. Catechins were

Table 5

Content of selected polyphenols (μg g^{-1} DM) in Virginia fanpetals herbage and silage

Specification	Herbage (n=9)				Silage (n=9)				SEM
	A	B	C	Total	A	B	C	Total	
Ferulic acid	2.25	3.71	0.45	6.42	0.23	0.36	0.34	0.93	0.10
p-Coumaric acid	18.4	112	3.28	134	0.69	1.44	0.59	2.72	1.91
Vanillic acid	11.9	18.6	18.6	49.1	21.0	11.2	3.08	35.3	3.77
Quercetin	10.2	5.02	637	652	290	1.01	1.48	292	28.4
Isorhamnetin	0.27	0.09	10.7	11.1	2.71	0.02	0.16	2.90	0.36
Catechin	13.3	2.65	1.62	17.6	0.00	0.00	0.00	0.00	0.99
Apigenin	0.02	0.07	0.16	0.26	0.03	0.03	0.07	0.13	0.01
Luteolin	0.93	0.23	5.74	6.90	3.44	0.57	0.58	4.60	0.25

A – free form, B – released by alkaline hydrolysis, C – released by acid hydrolysis, SEM – standard error of the mean

completely eliminated during ensiling. Quercetin predominated in both herbage and silage, and its content decreased by 45% during ensiling. The quercetin content of *Sida hermaphrodita* was similar to that reported by LIGAI and BANDYUKOVA (1990). Quercetin was the predominant polyphenol in both herbage (65.2 mg 100 g^{-1} DM) and silage (29.2 mg 100 g^{-1} DM). Ensiling decreased quercetin concentration to the level noted in buckwheat (DIETRICH et al. 2004).

CONCLUSIONS

Harvesting at the stage of bud formation resulted in a low-lignified NDF and CP content, similar to that in alfalfa. As a result of ensiling, the plant undergoes intensive proteolysis, like alfalfa, which reduces the protein value. Ensilaging resulted in an increase in UFA, accompanied by a decrease in MUFA. The MUFA content of *Sida hermaphrodita* silage was highly similar to that in alfalfa silage. *Sida hermaphrodita* had less of macronutrients and micronutrients compared to alfalfa. The research suggests that should be study use of *Sida hermaphrodita* silage in ruminant nutrition.

REFERENCES

Antoszkiewicz Z., Fijałkowska M., Mazur-Kuśnirek M., Przemieniecki S., Purwin C. 2019. *Effect of a harvest date and cutting height on the concentrations of carotenoids and tocopherols in Virginia fanpetals (Sida hermaphrodita) herbage and silage.* J. Elem., 24(4): 1195-1202. DOI: 10.5601/jelem.2019.24.2.1857

Borkowska H., Molas R. 2012. *Two extremely different crops, Salix and Sida, as sources of renewable bioenergy.* Biomass Bioenerg., 36: 234-240. DOI: 10.1016/j.biombioe.2011.10.025

Borkowska H., Molas R. 2013. *Yield comparison of four lignocellulosic perennial energy crop species.* Biomass Bioenerg., 51: 145-153. DOI: 10.1016/j.biombioe.2013.01.017

Boufaied H., Chouinard P.Y., Tremblay G.F., Petit H.V., Michaud R., Belanger G. 2003. *Fatty acids in forages.* I. *Factors affecting concentrations.* Can. J. Anim. Sci., 83: 501-511. DOI: 10.4141/A02-098

Chrenkova M., Čerešňakova Z., Weisbjerg M.R., Formeloval Z., Polačikova M., Vondrakova M. 2014. *Characterization of proteins in feeds according to the CNCPS and comparison to in situ parameters.* Czech. J. Anim. Sci., 59: 288-295.

Dietrich H., Rechner C.D., Patz C.D. 2004. *Bioactive compounds in fruit and juice.* Fruit. Proc., 1: 50-55.

Fijałkowska M., Przemieniecki S.W., Kurowski T., Lipiński K., Nogalski Z., Purwin C. 2017. *Ensiling suitability and microbiological quality of Virginia fanpetals biomass.* Can. J. Anim. Sci., 97: 541-544. DOI: 10.1139/cjas-2016-0175

Gąsior R. 2002. *Determination of volatile fatty acids and lactic acid in silage and ruminal digesta.* Information Newsletter. Quarterly published by the National Research Institute of Animal Production, Balice (in Polish).

Givens D.I., Rulquin H. 2004. *Utilization by ruminants of nitrogen compounds in silage-based diets.* Anim. Feed Sci. Technol., 114: 1-18. DOI: 10.1016/j.anifeedsci.2003.09.005

Halmemies-Beauchet-Filleau A., Rinne M., Lamminen M., Mapato C., Ampapon T., Wanapat M., Vanhatalo A. 2018. *Alternative and novel feeds for ruminants: nutritive value, product quality and environmental aspects.* The Animal Consortium, 12: 295-309. DOI: 10.1017/ /S1751731118002252

Jeż M., Wiczkowski W., Zielińska D., Białobrzewski I., Błaszczak W. 2018. *The impact of high pressure processing on the phenolic profile, hydrophilic antioxidant and reducing capacity of purée obtained from commercial tomato varieties.* Food Chem, 261: 201-209. DOI: 10.1016/ /j.foodchem.2018.04.060

Kostulak–Zielińska M., Potkański A. 2011. *Quality of baled grass-clover silages ensiled with chemical additives. Chemical composition.* Ann. Anim. Sci., 1: 153-165.

Kung L.Jr., Muck R.E. 2006. *Preservation protein during harvest and storage.* J. Dairy Sci., 89: 449.

Licitra G., Hernandez T.M., Van Soest P.J. 1996. *Standardization of procedures for nitrogen fractionation of ruminant feeds.* Anim. Feed Sci. Technol., 57: 347-358. DOI: 10.1016/0377--8401(95)00837-3

Ligai L.V., Bandyukova V.A. 1990. *Constituents of aerial parts of Sida hermaphrodita.* Khimija prir Soyedineniy, 2: 269-270.

Luchini N.D., Broderick G.A., Muck R.E., Makoni N.F., Vetter R.L. 1997. *Effect of storage system and dry matter content on the composition of alfalfa silage.* J. Dairy Sci., 80: 1827-1832. DOI: 10.3168/jds.S0022-0302(97)76117-4

Marković J., Štrbanović R., Cvetković M., Anđelković B., Živković B. 2009. *Effects of growth stage on the mineral concentrations in alfalfa (Medicago sativa* L.*) leaf, stem and the whole plant.* Biotech. Anim. Husb., 25: 1225-1231.

Nahm M., Morhart C. 2018. *Virginia mallow (Sida hermaphrodita (L.) Rusby) as perennial multipurpose crop: biomass yields, energetic valorization, utilization potentials, and management perspectives.* GCB Bioenergy, 10: 393-404. DOI: 10.1111/gcbb.12501

National Research Council Nutrient Requirements of Dairy Cattle. 2001. 7th Rev. Ed., Washington, DC, The National Academies Press.

Papadopoulos Y.A., McKersie B.D. 1983. *A comparison of protein degradation during wilting and ensiling of six forage species.* Can. J. Plant. Sci., 63: 903-912. DOI: 10.4141/cjps83-114

Porter M.G., Murray R.S. 2001. *The volatility of components of grass silage on oven drying and the inter-relationship between dry-matter content estimated by different analytical methods.* Grass Forage Sci., 56: 405-411. DOI: 10.1046/j.1365-2494.2001.00292.x

Purwin C., Fijałkowska M., Lipiński K., Wierzbowska J., Kobzhassarov T.Z., Michalski J. 2015. *Changes in amino acid composition during the ensiling of lucerne and red clover in round bales.* J. Elem., 20: 965-973. DOI: 10.5601/jelem.2015.20.1.863

Purwin C., Fijałkowska M., Pysera B., Lipiński K., Sienkiewicz S., Piwczyński D., Puzio N. 2014. *Nitrogen fractions and amino acid content in alfalfa and red clover immediately after cutting and after wilting in the field.* J. Elem., 19: 723-734. DOI: 10.5601/jelem.2014.19.2.692

Purwin C., Pysera B., Tokarczyk M., Sederevičius A., Savickis S., Traidaraitė A. 2009. *Production results of dairy cows fed grass and alfalfa silage with a different degree of wilting.* Vet. Med. Zoot., 46: 60-66. DOI:

Rezaei J., Rouzbehan Y., Fazaeli H. 2009. *Nutritive value of fresh and ensiled amaranth (Amaranthus hypochondriacus) treated with different levels of molasses.* Anim. Feed Sci. Technol., 151: 153-160. DOI: 10.1016/j.anifeedsci.2008.12.001

Tarkowski A., Truchliński J. 2011. *Nutritional value of Virginia fanpetals (Sida hermaphrodita Rusby) protein in evaluation of nitrogen fertilization effect on environment.* New Medicine, 1: 8-11.

Tarkowski A. 2003. *Utilization of Sida forage (Sida hermaphrodita) for silage.* Ann. UMCS, Sect. EE, Zootech, 83: 229-234. (in Polish)

Thomas T.A. 1977. *An automated procedure for the determination of soluble carbohydrates in herbage.* J. Sci. Food Agr., 28: 639-642. DOI: 10.1002/jsfa.2740280711

Van Rast G., Fievez V., De Riek J., Van Bockstaele E. 2009. *Influence of ensiling forages at different dry matters and silage additives on lipid metabolism and fatty acid composition.* Anim. Feed Sci. Technol., 150: 62-74. DOI: 10.1016/j.anifeedsci.2008.08.004

Van Soest P.J., Robertson J.B., Lewis B.A. 1991. *Methods of dietary fiber, neutral detergent fiber and nonstarch polysaccharides in relation to animal nutrition.* J. Dairy Sci., 74: 3583-3597. DOI: 10.3168/jds.S0022-0302(91)78551-2

Wiczkowski W., Szawara-Nowak D., Sawicki T., Mitrus J., Kasprzykowski Z., Horbowicz M. 2016. *Profile of phenolic acids and antioxidant capacity in organs of common buckwheat sprout.* Acta Aliment, 45: 250-257. DOI: 10.1556/066.2016.45.2.12

Winters A.L., Fychan R., Jones R. 2001. *Effect of formic acid and a bacterial inoculant on the amino acid composition of grass silage and on animal performance.* Grass Forage Sci., 56: 181-192. DOI: 10.1046/j.1365-2494.2001.00265.x