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THE QUALITY OF GREEN MASS AND SILAGE FROM *Amaranthus hypochondriacus* GROWNING UNDER THE CONDITIONS OF THE REPUBLIC OF MOLDOVA

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Abstract

The identification of alternative crops that need less water and produce increased yields of organic matter per unit of water is important for agricultural sustainability. Amaranthus species are C_4 dicotyledonous plants characterized by effective photosynthesis, intensive nitrogen metabolism and good adaptability. The aim of this paper was to evaluate some biological peculiarities, the quality of green mass and produced silage from Amaranthus hypochondriacus, as well as the possibility of using it as feed for ruminant animals and as feedstock for the production of biomethane. The results of our rJesearch revealed that the dry matter of harvested whole plants contained 172 g/kg CP, 330 g/kg ADF, 462 g/kg NDF, 55 g/kg ADL, 68 g/kg TSS and 88 g/kg ash, 275 g/kg Cel and 132 g/kg HC with 10.22 MJ/kg metabolizable energy and 6.23 MJ/kg net energy for lactation. The prepared silage was characterized by agreeable colour with pleasant smell and pH 3.86, it contained 13.4 g/kg DM lactic acid, 5.8 g/kg DM acetic acid, 877.6 g/kg DM organic matter, 167 g/kg CP, 348 g/kg ADF, 516 g/kg NDF, 45 g/kg ADL, 303 g/kg Cel and 156 g/kg HC with 10.05 MJ/kg metabolizable energy and 6.02 MJ/kg net energy for lactation. It has been found that the biomethane potential of the Amaranthus hypochondriacus biomass varied from 282 to 303 l/kg ODM. Amaranthus hypochondriacus contains many nutrients, which make it suitable to be used as fodder for animals and has potential as feedstock for biomethane production.

Key words: *Amaranthus hypochondriacus, biochemical composition, biomethane potential, fodder value, green mass, silage.*

INTRODUCTION

The ever-growing human population is expected to reach nine billion persons in the coming decades, imposing the need for urgent solutions to increase food supplies. Human activities require energy to power the systems of production, transportation, heating and cooling, at the same time, fossil fuel consumption increased atmospheric CO_2 concentrations with important impacts on the global climate. Climate change generates serious problems in the environment causing soil degradation and erosion, water pollution and biodiversity decline. One critical measure to ensure future food availability for all is to provide more diverse food sources and develop agricultural systems that are resistant to climate change.

The diversification of crops and of the systems in which they grow are essential for agriculture and can make it sustainable, resilient, and suitable for local environments and soils. The cultivation of neglected and underused crops and the domestication of new species would promote agricultural diversity and could provide a solution to many of the problems associated with food security, nutrition, healthcare, medicine and industrial needs. A leading strategy is to fulfill the potential of plant species with C_4 photosynthetic pathway. Most of these species have high nutritional value, are water use efficient and are able to withstand drought, flooding, extreme temperatures, and pests and diseases.

Amaranths are among the group of dicotyledonous C_4 plants, characterized by atriplicoid type Kranz anatomy of leaves, cotyledons and bracts (Sage et al., 2007). They are characterized by effective photosynthesis, intensive nitrogen metabolism and a good adaptability, which can grow in the poor soils and areas with high temperature and limited rainfall.

Amaranth was cultivated by early civilisations over 2000 years ago in America and continues to be used commonly worldwide up to our days. Sauer (1967) reports the introduction of amaranth into Spain in 16-th century, from where it had spread throughout the Europe, around 1700s, it was known as a minor grain plant in central Europe and Russia.

The genus *Amaranthus* L. belongs to the *Amaranthoidae* subfamily of the *Amaranthaceae* family, *Caryophyllales* order and includes 105 species. Some of the amaranth species domesticated for grain production: *Amaranthus hypochondriacus, Amaranthus cruentus* and *Amaranthus caudatus*; while those grown for leaf vegetables are: *Amaranthus dubius, Amaranthus blitum, Amaranthus tricolor, Amaranthus viridis* and *Amaranthus hybridus* (Das, 2016). Amaranthus seeds being a rich source of fatty acids, proteins, micronutrients, vitamins and squalene, are used as cereals, which are consumed whole toasted or milled into flour. The pigments obtained from all the parts amaranth plants can be used as a food or pharmaceutical dye. Many species of the *Amaranthus* genus are medicinally important and bear antiallergic, anticancer, antihypertensive and antioxidant properties, thus being used in the treatment of several aliments (Assad et al., 2017). Amaranths has also been used in many countries as a grain, forage or silage crop for many animals, including cattle, chickens, pigs and rabbits as an alternative protein and fibre source and as a bioactive component (essential fatty acids, flavonoids, stanols, tocotrienols and squalene) source (Peiretti, 2018). Feeding amaranth silage to cows increases the milk productivity by 11.9%, milk fat by 0.46% and milk protein by 0.18 % as compared with corn silage (Pavlenkova et al., 2019). Von Cossel (2019) observed that the flowers of amaranth attracted numerous insect species such as wild bees, honey bees and bumblebees, are expected to have a higher benefit of amaranth stands compared to maize stands.

As a result of the research conducted in Botanical Garden Chişinău it has been found that the species *Amaranthus cruentus* and *Amaranthus mangostanus* are tolerant to drought and have a high productivity of fresh mass that allows obtaining 5.31-6.68 t/ha nutritive units and 841-926 kg/ha digestible protein (Teleuţă, 1995; Ţîţei & Teleuţă, 1995). Marin et al. (2011) reported that, in the central part of the Romanian Plain, the recorded green mass yield of the studied cultivars was 43.1 t/ha for *Amaranthus hypochondriacus* and 46.7 t/ha for *Amaranthus cruentus;* the grain productivity of *Amaranthus hypochondriacus* was 4576 kg/ha and *Amaranthus cruentus* - 4609 kg/ha. Toader & Roman (2009) found that the chemical composition of grains *Amaranthus hypochondriacus* cultivars was following: 15.73-17.83% proteins, 60.75-62.83% starch, 5.17-6.49% lipids, 4.34-4.93% fibres and 3.31-3.93% ash. Rivelli et al. (2008) mentioned that, under the irrigation conditions of southern Italy, the total aboveground dry matter of tested *Amaranthus* species ranged from 15 t/ha (*Amaranthus cruentus*) to 23 t/ha (*Amaranthus hypochondriacus*).

The aim of this study was to evaluate some biological peculiarities, the quality of green mass and silage produced from *Amaranthus hypochondriacus*, as well as the possibility of using it as feed for ruminant animals and as feedstock for the production of biomethane.

MATERIALS AND METHODS

The non-native species *Amaranthus hypochondriacus*, which was cultivated in the experimental plot of the "Alexandru Ciubotaru" National Botanical Garden (Institute) Chişinău N 46°58′25.7″ latitude and E 28°52′57.8″ longitude, served as subject of the research, and the C_4 fodder crops corn, *Zea mays*, and Sudangrass, *Sorghum sudanense*, were used as controls.

The green mass of the *Amaranthus hypochondriacus* and *Sorghum sudanense* was mowed in early flowering stage (July), but the *Zea mays* - in kernel milk-wax stage (middle August). The green mass productivity was determined by weighing the yield obtained from a harvested area of 10 m^2, which was afterwards transformed per hectare. The leaves/stems ratio was determined by separating leaves and panicles from the stem, weighing them separately and establishing the ratios for these quantities, samples of 1.0 kg harvested plants were used. For chemical analyses, the samples were dried at 65 ± 5°C. The dry matter content was detected by drying samples up to constant weight at 105°C. The silage was prepared and evaluated in accordance with the Moldavian standard SM 108. Some assessments of the main biochemical parameters: protein, ash, acid detergent fibre (ADF), neutral detergent fibre (NDF) and acid detergent lignin (ADL), total soluble sugars (TSS), digestible dry matter (DDM), digestible organic matter (DOM) have been determined by near infrared spectroscopy (NIRS) technique PERTEN DA 7200 of the Research and Development Institute for Grasslands Braşov, România. The concentration of hemicellulose (HC) and cellulose (Cel), the relative feed value (RFV), the digestible energy (DE), the metabolizable energy (ME) and the net energy for lactation (NEl) were calculated according to standard procedures.

The carbon content of the substrates was calculated from data on volatile solids, using an empirical equation indicated by Badger et al. (1979). The biochemical biogas potential (Yb) and the methane potential (Ym) were calculated according to the equations of Dandikas et al. (2014) based on the chemical compounds – acid detergent lignin (ADL) and hemicellulose (HC) values:

$$Yb = 727 + 0.25\ HC - 3.93\ ADL$$

$$Ym = 371 + 0.13\ HC - 2.00\ ADL$$

RESULTS AND DISCUSSIONS

The results of our study revealed that the seedlings of *Amaranthus hypochondriacus* emerged uniformly on the soil surface 3-5 days after sowing. In early stages, amaranth plantlets were characterized by slower growth of the stem and leaves, than corn and Sudangrass plantlets. We noticed that the growth and development rate of the aerial part increased 25 days after the emergence of the seedlings. The *Amaranthus hypochondriacus* root system developed actively from the seedling to the flowering period, the strong taproot grew over 1.7-2.0 m in depth and the lateral roots on the upper part - 35-40 cm. Plant height, stem thickness and leaves/stems ratio have significant impact on the yield, but also affect the quality of the phytomass. Results regarding some bio-morphological characteristics of the studied species and the structure of the harvested phytomass are presented in Table 1. At the time of the harvest, the *Amaranthus hypochondriacus* plants (160 cm) were shorter than *Zea mays* (239 cm) and *Sorghum sudanense* plants (212 cm), but amaranth stems, at the base, were about as thick as corn stems and three times thicker than Sudangrass. The productivity of *Amaranthus hypochondriacus* harvested in early flowering stage, late July, achieved 6.85 kg/m^2 green mass or 1.04 kg/m^2 dry matter, the annual yield of Sudan grass from two harvests (cuts) – 3.63 kg/m^2 green mass or 0.94 kg/m^2 dry matter, but the productivity of *Zea mays* reached 4.09 kg/m^2 green mass or 1.22 kg/m^2 dry matter, due to the high content of cobs in plant structure of the harvested phytomass in middle August. The harvested amaranth biomass was characterised by higher content of leaves (54%), but lower amount of dry matter (18%) in contrast with the control variants.

The biochemical composition, the nutritive and energy value of the green mass of the tested C_4 species are shown in Table 2. Analyzing the results of the green mass quality, we could mention that the concentrations of nutrients in *Amaranthus hypochondriacus* plants were 172 g/kg CP, 330 g/kg ADF, 462 g/kg NDF, 55 g/kg ADL, 68 g/kg TSS and 88 g/kg ash; *Sorghum sudanense* contained 85-101 g/kg CP, 372-413 g/kg ADF, 593-656 g/kg NDF, 39-41 g/kg ADL, 136-138 g/kg TSS and 95-97 g/kg ash, but *in Zea mays* - 62 g/kg CP, 310 g/kg ADF, 510 g/kg NDF, 51 g/kg ADL, 210 g/kg TSS and 60 g/kg ash, respectively. Thus, amaranth green mass contained a very high amount of crude protein and lower content of total soluble sugars than Sudangrass and corn. The digestibility of amaranth dry matter reached 57.1%, higher than Sudangrass, but significantly lower than corn dry matter. The nutritive and energy value of *Amaranthus hypochondriacus* was RFV= 127, 12.44 MJ/kg DE, 10.22 MJ/kg ME and 6.23 MJ/kg NEl, but the controls: *Sorghum sudanense* - RFV=80-94, 10.39-11.92 MJ/kg DE, 8.52-9.79 MJ/kg ME, 5.29-5.75 MJ/kg NEl and *Zea mays* RFV= 116, 12.72 MJ/kg DE, 10.75 MJ/kg ME, 6.46 MJ/kg NEl, respectively. The calculated annual crude protein yield of amaranth natural fodder may be 1910 kg/ha, Sudangrass - 830 kg/ha and corn fodder - 760 kg/ha, respectively.

Several literature sources describe the nutritional value of *Amaranthus hypochondriacus* plants. The results obtained by Pisaoikova et al. (2006) in the Czech Republic, varied in the advancing stage of regrowth, from 80 to 120 days: 183.6-113.1 g/kg CP, 14.8-33.2 g/kg EE, 163.5-233.7 g/kg CF, 445.9-481.6.0 g/kg NFE, 192.2-138.4 g/kg ash, 17.2-18.4 MJ/kg GE.

Table 1. Some bio-morphological characteristics and the structure of the harvested phytomass of the studied species

Indices	*Amaranthus hypochondriacus*	*Sorghum sudanense*		*Zea mays*
		First cut	Second cut	
Plant height, cm	160	212	163	239
Stem thickness, mm	20	7	8	21
Leaf fresh mass, g/tiller	440.1	12.5	21.2	151.6
Leaf dry matter, g/tiller	87.6	3.2	6.1	46.4
Stem fresh mass, g/tiller	449.8	33.1	44.4	320.2
Stem dry matter, g/tiller	63.9	7.1	11.1	94.5
The yield :				
- fresh mass, kg/m^2	6.85	2.79	0.84	4.09
- dry matter, kg/ m^2	1.04	0.72	0.22	1.22

Table 2. The biochemical composition, the nutritive and the energy value of the green mass

Indices	*Amaranthus hypochondriacus*	*Sorghum sudanense*		*Zea mays*
		First cut	Second cut	
Crude protein, g/kg	172	85	101	62
Acid detergent fibre, g/kg DM	330	413	372	310
Neutral detergent fibre, g/kg DM	462	656	593	520
Acid detergent lignin, g/kg DM	55	41	39	51
Total soluble sugars, g/kg DM	68	138	136	210
Crude ash, g/kg DM	88	95	97	60
Digestible dry matter, % DM	57.1	51.7	60.3	72.3
Digestible organic matter, % DM	51.4	50.6	58.1	68.3
Digestible energy, MJ/kg DM	12.45	10.39	11.92	12.72
Metabolizable energy, MJ/kg DM	10.22	8.52	9.79	10.75
Net energy for lactation, MJ/kg DM	6.23	5.28	5.75	6.46
Relative feed value	127	80	94	116
Potential crude protein, kg/ha	1910	610	220	760

According to Rahnama & Safaeie (2017), *Amaranthus hypochondriacus* can produce 75.86-90.30 t/ha fresh and 11.0-13.05 t/ha dry forage yield with 11.5-12.00% protein, 2.1-2.4% fats, 67.4-69.1% DMD, RFV 157.1-171.5, RFQ 158-174.6. Leukebandara et al. (2015) mentioned that the *Amaranthus hypochondriacus* plants harvested the mid-bloom stage contained 13.20% DM, 18.43% CP, 3.17% EE, 24.50% CF, 16.83% ash; *Amaranthus cruentus* - 13.87% DM, 16.00% CP, 3.60% EE, 24.50% CF, 15.33% ash; *Amaranthus caudatus* - 13.43% DM, 14.30% CP, 2.90% EE, 21.80% CF, 13.60% ash, and *Zea mays* - 18.27% DM, 8.13% CP, 2.43% EE, 25.70% CF, 5.07% ash. The results obtained by Biel et al. (2017) on feed value of *Amaranthus hypochondriacus* aerial part were as follows: 101 g/kg CP, 17.6 g/kg EE, 240 g/kg DM CF, 440 g/kg NDF, 332 g/kg ADF, 63.1 g/kg lignin, 269 g/kg Cel, 109 g/kg HC, 144 g/kg ash, 13.7 g/kg calcium and 6.8 g/kg phosphorus, 63.8% DMD, 10.8 MJ/kg DE and 8.7 MJ/kg ME. Pospisil et al. (2009) studied the nutrient and fibre composition in flowering stage and found that *Amaranthus hypochondriacus* contained 85-113 g/kg CP, 60-91 g/kg DP, 13-20 g/kg EE, 239-290 g/kg CF, 423-478 g/kg NDF, 301-366 g/kg ADF, but sorghum forage contained 64-92 g/kg CP, 43-65 g/kg DP, 19-21 g/kg EE, 295-329 g/kg CF, 637-659 g/kg NDF, 352-389 g/kg ADF. Abbasi et al. (2018) reported that fresh amaranth forage contained 233 g/kg DM, 187 g/kg CP, 420 g/kg NDFom, 275 g/kg ADFom, 44.6 g/kg ADL, 57 g/kg EE, 62.5 g/kg water-soluble carbohydrates, 145 g/kg ash, 11.1 g/kg calcium, 6.6 g/kg phosphorus and 8.4 MJ/kg ME.

Silage is commonly used as fodder, as high-quality roughage for farm animals, but in recent decades, it has also been used as substrate in biogas production. During the sensorial assessment, it was found that the prepared silage from *Amaranthus hypochondriacus* green biomass had a pleasant smell, specific to pickled vegetables, the consistency of the silage was retained, in comparison with the initial green mass, without mould and mucus. The fermentation quality of prepared silages is illustrated in Table 3. The performed analysis helped determining that the pH index varied unessentially from 3.61 in corn silage to 3.86 in amaranth silage. The pH index of the prepared silages from the studied species met the standard SM 108 for the first class quality. The greatest differences were obtained in concentrations of organic acids. It has been determined that the content of total organic acids was low in *Amaranthus hypochondriacus* silage – 19.2 g/kg, in comparison with corn and Sudangrass silages. Butyric acid was not detected in the amaranth and corn silages. The *Amaranthus hypochondriacus* silage was characterised by high content of acetic acid (5.8 g/kg) and lower concentration of lactic acid (13.4 g/kg). The dry matter content in the silage prepared from *Amaranthus hypochondriacus* was low (184 g/kg) in comparison with *Zea mays* silage (314.5 g/kg). The results of the study on nutrient concentrations indicate that *Amaranthus hypochondriacus* silage contained 167 g/kg CP, 122 g/kg ash, 516 g/kg NDF, 348 g/kg ADF, 45 g/kg ADL, 12 g/kg TSS. *Sorghum sudanense* silage prepared after the first cut contained 57 g/kg CP, 109 g/kg ash, 402 g/kg ADF, 652 g/kg NDF, 39 g/kg ADL, 108 g/kg TSS and *Zea mays* silage – 53 g/kg CP, 50 g/kg ash, 514 g/kg NDF, 303 g/kg ADF, 276 g/kg TSS. It was found that during the process of ensiling, the concentrations of crude protein in *Amaranthus hypochondriacus* silage had not modified in comparison with the initial mass, but it had decreased essentially in controls silages. In both silages, the lignin content decreased and the digestibility of nutrients was higher in comparison with the initial mass. In *Amaranthus hypochondriacus* silage, the concentrations of energy reached very acceptable values: 10.05 MJ/kg ME and 6.02 MJ/kg NEl, as compared with *Sorghum sudanense* silage - 9.38 MJ/kg ME and 5.54 MJ/kg NEl, however, they were lower than in *Zea mays* silage - 10.52 MJ/kg ME and 5.54 MJ/kg NEl.

Some authors mentioned various findings about the silage quality of studied species. According to Herrmann et al. (2016), the biochemical composition of *Amaranthus* silages were 9.4-9.6% CP, 3.3-3.6% EE, 42.9-50.5% NFE, 35.2-44.7% NDF, 30.2-37.6% ADF, 4.0-6.3% ADL, 5.8-9.1% lactic acid, 1.1% acetic acid, pH 4.1-4.2; *Zea mays* silage - 4.4-12.1% CP, 1.0-3.9% EE, 53.8-71.4% NFE, 26.8-53.7% NDF, 14.3-37.1% ADF, 1.0-6.1% ADL, 3.5-9.5% lactic acid, 0.2-3.6% acetic acid, pH 3.1-4.1; *Sorghum bicolo*r x *S. sudanense* silage – 5.3-17% CP, 0.5-3.2% EE, 40.8-58.4% NFE, 48.2-69.1% NDF, 28.5-42.7% ADF, 2.9-7.2% ADL, 2.5-12.0% lactic acid, 0.3-2.4% acetic acid, pH 3.2-5.5. Abbasi et al. (2018) found that the ensiled amaranth forage, without additives, was characterized by 250 g/kg DM, pH 4.49, 57 g/kg lactic acid, 17.1 g/kg acetic acid and 0.3 g/kg butyric acid, 171 g/kg CP, 400 g/kg NDFom, 267 g/kg ADFom, 43.0 g/kg ADL, 103 g/kg EE, 19.7 g/kg water-soluble carbohydrates, 170 g/kg ash, 10.8 g/kg calcium, 5.8 g/kg phosphorus and 8.4 MJ/kg ME. Rezaei et al. (2015) reported that amaranth silage had pH 3.99, 23.5% DM, contained 69.1 g/kg lactate, 19.3 g/kg acetate, 10.3 g/kg butyrate, 114 g/kg CP, 451g/kg NDFom, 310 g/kg ADFom, 35.6 g/kg lignin with 676 g/kg DOM and 9.34 MJ/kg ME, the corn silage - pH 4.0, 22.4% DM, 71.8 g/kg lactate, 20.4 g/kg acetate, 0.87 g/kg butyrate, 83 g/kg CP, 510 g/kg NDFom, 335 g/kg ADFom, 45.7 g/kg lignin with 661 g/kg DOM and 9.71 MJ/kg ME. Rahjerdi et al. (2015) compared the ensilability of *Amaranthus hypochondriacus* and corn and pointed out that, the amaranth silage had pH 4.10-4.25 and 23.0-23.4% DM, contained 6.10-6.24% lactic acid, 1.18-1.20% acetic acid, 0.031-0.047% butyric acid, 12.0-12.8% CP, 40.0-41.9% NDFom, 26.0-27.2% ADFom, 3.13-3.21% ADL, 2.36-2.68% EE, 13.6-14.0% ash, the corn silage - pH 3.82 and 22.0% DM, it contained 8.02% lactic acid, 1.74% acetic acid, 0.005% butyric acid, 6.98% CP, 52.89% NDFom, 32.7% ADFom, 4.88 % ADL, 1.98% EE, 6.28% ash. Ma et al. (2019) concluded that the dry matter and the chemical composition of amaranth silage varied depending on the time when the plants had been harvested and ensiled: 15.31-22.00% DM, 13.21-11.51% CP, 47.88-54.14% NDF, 29.79-39.03% ADF, 2.53-4.67% ADL.

Table 3. The fermentation quality of the silages from the studied species

Indices	*Amaranthus hypochondriacus*	*Sorghum sudanense*	*Zea mays*
pH index	3.86	3.82	3.61
content of organic acids, g/kg DM	19.2	30.0	32.8
free acetic acid, g/kg DM	2.7	2.3	1.3
free butyric acid, g/kg DM	0.0	0.0	0.0
free lactic acid, g/kg DM	6.0	10.2	13.7
fixed acetic acid, g/kg DM	3.1	2.1	2.0
fixed butyric acid, g/kg DM	0.0	0.2	0.0
fixed lactic acid, g/kg DM	7.4	15.2	15.8
total acetic acid, g/kg DM	5.8	4.4	3.3
total butyric acid, g/kg DM	0.0	0.2	0.0
total lactic acid, g/kg DM	13.4	28.4	29.5
acetic acid, % of organic acids	30	15	10
butyric acid, % of organic acids	0	1	0
lactic acid, % of organic acids	70	84	90

Table 4. The biochemical composition and the feed value of the silages from the studied species

Indices	*Amaranthus hypochondriacus*	*Sorghum sudanense* (first cut)	*Zea mays*
Crude protein, g/kg DM	167	57	53
Acid detergent fibre, g/kg DM	348	402	303
Neutral detergent fibre, g/kg DM	516	652	514
Acid detergent lignin, g/kg DM	45	39	46
Total soluble sugars, g/kg DM	12	108	276
Crude ash, g/kg DM	123	109	50
Digestible dry matter, %	61.8	57.5	72.4
Digestible organic matter, %	51.3	53.8	68.5
Digestible energy, MJ/ kg DM	12.2	11.43	12.82
Metabolizable energy, MJ/ kg DM	10.2	9.38	10.52
Net energy for lactation, MJ/ kg DM	6.03	5.54	6.54
Relative feed value	111	82	118
Potential crude protein, kg/ha	1650	390	620

Biomass is an important source for the production of multi-purpose renewable energy. The production of biogas using lignocellulosic biomass as a renewable energy source is both sustainable and environmentally friendly. The stability and the productivity of biogas digesters are mostly influenced by biochemical composition, biodegradability and ratio of carbon and nitrogen of substrate. The optimal C/N ratio in biomass should range from 10 to 30, which does not affect the development of microflora involved in anaerobic digestion. The results regarding of the quality of the substrate and its biochemical methane potential from the studied species are shown in Table 5. We would like to mention that in the green mass and silage substrates from *Amaranthus hypochondriacus* plants, the carbon and nitrogen ratio was 18, but in Sudangrass substrates C/N = 39-41 and in corn substrates C/N = 46-51. It has been found that the concentration of hemicellulose in amaranth silage substrates increases by 26 g/kg, but lignin decreases by 10 g/kg DM in comparison with amaranth green mass substrates, and thus it has a positive impact on methane yield. The calculated biomethane potential of the amaranth silage substrates was 302 l/kg, but – of amaranth green mass substrates 278 l/kg, the annual methane potential productivity achieved 2760 m^3/ha. The biomethane potential of the Sudangrass substrates was 319-326 l/kg, but of corn substrates 296-306 l/kg.

Table 5. The biochemical composition and the biomethane production potential of substrates from the studied species

Indices	*Amaranthus hypochondriacus*		*Sorghum sudanense*		*Zea mays*	
	green mass	silage	green mass	silage	green mass	silage
Nitrogen, g/kg DM	27.52	26.72	13.62	9.12	9.92	8.51
Carbon, g/kg DM	50.66	48.77	50.27	49.50	52.22	54.00
Ratio carbon/nitrogen	18.41	18.25	37.00	54.28	52.61	63.45
Cellulose, g/kg DM	275	303	272	363	259	257
Hemicellulose, g/kg DM	132	158	243	250	210	211
Acid detergent lignin, g/kg DM	55	45	41	39	51	46
Biogas potential, l/kg VS	544	590	627	637	580	599
Biomethane potential, l/kg VS	278	302	319	326	296	306

Several literature sources describe the methane potential of amaranth substrate. Seppälä (2013) found that in boreal conditions the methane yield from amaranth biomass reached 290 l/kg VS or 2 700 m^3/ha, but from Sudangrass – 330 l/kg VS or 2 500 m^3/ha.

Mursec et al. (2009) remarked that methane production from amaranth silage was 125 l/kg VS, maize and sorghum silages 187-188 l/kg VS. Eberl et al. (2014) reported that the amaranth silage was characterized by a poor dry mater content (23.6%) accompanied by high contents of ash (13.7% of VS), ADL (5.8% of VS) and cellulose (26% of VS), which caused a much lower specific methane yield (270 l/kg) compared to maize (350 l/kg). Based on the batch experiments, Dubrovskis & Adamovics (2015) found that the average methane yield per unit of dry organic matter added from digestion of amaranth silage was 403 L/kg, with catalyst Metaferm 434-484 L/kg.

Herrmann et al. (2016), reported that the tested amaranth silage substrate had C/N = 27-27 and 4.0-6.3% lignin, methane content in biogas 58.4-59.1%, biochemical methane potential 268.9-287.9 l/kg VS; corn silages - C/N = 23-61 and 1.0-6.1% lignin, the methane content in biogas 53.1-58.4%, biochemical methane potential 294.5-376.2 l/kg; Sudangrass hybrid silages had C/N = 15-54 and contained 1.0-6.1% lignin, methane content in biogas 53.6-61.1%, biochemical methane potential 248.4-348.52 l/kg.

According to Von Cossel (2019), the specific methane yield of *Amaranthus hypochondriacus* substrate was on average 266 l/kg VS, which was negatively affected by the high contents of ash (13.6%), lignin (6.5%) and cellulose (32.9%).

CONCLUSIONS

The yield of *Amaranthus hypochondriacus* harvested in early flowering period is about 6.85 kg/m^2 green mass or 1.04 kg/m^2 dry matter.

The concentrations of nutrients and energy in *Amaranthus hypochondriacus* plants harvested in early flowering stage are 172 g/kg CP, 330 g/kg ADF, 462 g/kg NDF, 55 g/kg ADL, 68 g/kg TSS and 88 g/kg ash, RFV = 127, 12.44 MJ/kg DE, 10.22 MJ/kg ME and 6.23 MJ/kg NEl.

The *Amaranthus hypochondriacus* silage contains13.4 g/kg DM lactic acid, 5.8 g/kg DM acetic acid, 167 g/kg CP, 123 g/kg ash, 516 g/kg NDF, 348 g/kg ADF, 45 g/kg ADL, 12 g/kg TSS, 158 g/kg HC and 303 g/kg Cel, 10.05 MJ/kg ME and 6.02 MJ/kg NEl.

The biochemical methane potential of amaranth green mass substrates is 278 l/kg ODM and silage substrates - 302 l/kg ODM.

The green mass and silage obtained from *Amaranthus hypochondriacus* contain many nutrients, which make them suitable to be used as fodder for animals and have high potential as feedstock for biomethane production.

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