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EFFECTS OF LOCATION AND AGRO-ECOLOGICAL CONDITIONS ON THE CHEMICAL COMPOSITION AND QUALITY OF CORN SILAGE ON FAMILY FARMS

SUMMARY

This study was conducted from 2022 to 2024 on eight family dairy farms located in two distinct agro-ecological regions of the Republic of Srpska, with the objective to evaluate the effects of location and environmental conditions on the quality parameters of corn silage. The selected sites differed in their continental climate sub-types: a more humid variant prevailed in the Gradiška area (L1), whereas a drier continental climate characterized the Bijeljina area (L2). At each location, four representative farms (capacities ranging from 6 to 16 lactating cows) were selected, from which representative composite samples of corn silage were collected annually. The samples were analyzed to determine fermentation dynamics (pH), nutritional value indicators (dry matter, crude protein, crude fiber, crude ash), net energy for lactation (NEL), and particle size distribution using the Penn State Particle Separator (PSPS).

The results indicated that location exerted a highly significant effect on dry matter content, crude fiber, and energy value ($p<0.01$), as well as a significant effect on crude protein content ($p<0.05$). The year of production had a highly significant effect on the energy value ($p<0.01$) and a significant effect on the dry matter content ($p<0.05$). Throughout the study period, silage pH values remained stable and optimal, ranging from 3.60 to 4.26. The average dry matter content was significantly lower at location L2 (233.8–308.7 g kg^{-1} DM) compared to location L1 (318.7–392.8 g kg^{-1} DM). Consequently, the net energy for lactation (NEL) was superior at location L1, reaching up to 6.52 MJ kg^{-1} DM, compared to a minimum of 5.90 MJ kg^{-1} DM recorded at location L2. Structural analysis revealed systematic deviations in particle size distribution relative to recommended standards during the first two years of the study at location L2, with deviations amounting to 41.67% on the third sieve and 25.0% in the bottom pan. Similarly, during the first two years at location L1, a deviation of 25.0% was

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observed on both the third sieve and in the bottom pan, prior to complete stabilization in the final year of the experiment.

These findings highlight that while the technical processes of compaction and fermentation can be effectively standardized across farms, the forage maturity stage, heavily dictated by climatic factors, and the precise adjustment of the chopper's length of cut remain the critical practical determinants for maximizing ration energy density and preventing metabolic disorders in high-yielding dairy cows.

Keywords: corn silage, pH, dry matter, crude protein, ash, NEL

INTRODUCTION

Global climate changes, occurring on a broad scale, seriously threaten the stability of agricultural production and challenge the provision of sufficient amounts of food for humans and livestock (IPCC, 2023). The production of roughage in open areas, without irrigation possibilities, is under the severe impact of increasingly frequent extreme weather events, which directly jeopardizes the economic profitability of livestock farms (Ahamed *et al.,* 2023). Climate forecasting models for Bosnia and Herzegovina predict an increase in average annual air temperatures by 2–4 °C by the end of this century, while a temperature spike of up to 4.8 °C is expected during the summer months (UNDP, 2021). High temperatures induce pronounced physiological stress in cultivated plants, disrupting the processes of photosynthesis and transpiration, which results in a drastic decline in the yield and quality of biomass (Rehman *et al.,* 2025).

Smart water management in the agriculture of Bosnia and Herzegovina (BiH) is becoming a primary priority due to the rising demand for this resource and frequent agrometeorological extremes (Marković *et al.,* 2022), which induce a drastic decline in the yield and biomass quality of corn as the dominant crop in the region. Concurrently, a reduction in the total annual precipitation by approximately 30% is projected, with an observed precipitation deficit expected to reach up to 50% in the Posavina region and the southern parts of the Republic of Srpska (Knežević *et al.,* 2013). Recommendations for mitigating these climate extremes through advanced corn cultivation technologies in divergent agro-climatic years are detailed by Simić *et al., (*2018), who emphasize the importance of systemic adaptation of agrotechnical practices. According to official estimates by relevant institutions, a significant decline in cereal yields is expected across the Western Balkan countries. In the Gradiška area, water regime simulations confirm that under extreme heat stress conditions, the evapotranspiration deficit exceeds 30%, which, within current agricultural practices, leads to a relative loss in corn yield of up to 40%, accompanied by pronounced interannual variability (Soares *et al.,* 2026). Due to the global rise in temperatures, altered precipitation patterns, and the frequent occurrence of extreme climate events, adapting corn production technology and breeding plants for stress tolerance are proposed to mitigate negative production effects (Bekavac *et al.,* 2010). Extreme climate factors and heat stress disrupt physiological processes and molecular defense mechanisms in plants, which increases pathogen incidence and necessitates the implementation of climate-smart disease monitoring strategies to preserve production sustainability (Hossain *et al*., 2024).

In the Republic of Srpska, approximately 3,000 farms actively engaged in milk production and marketing were registered during 2025 (MAFWM RS, 2025). In the Gradiška area, dairy production is supported by 148 farms with a population of about 4,000 dairy cows, while in the territory of Bijeljina, around 1,100 milk producers owning approximately 6,000 dairy heads are registered. On the majority of these farms located in the lowland regions of the Republic of Srpska, whole-plant corn silage represents the dietary baseline, accounting for 30–50% of the roughage portion of the ration, while the remainder consists of hay and haylage. The exceptional significance of corn silage as a key feedstuff in the ration of lactating cows stems from its high biomass yield per unit area, minimal nutrient losses upon completion of fermentation, and its role in ensuring ration stability throughout the year (Harrison *et al*., 1994). An additional advantage of ensiling is reflected in the ability to harvest the crop at the optimal stage of morphological development and store the biomass in silo facilities until the moment of utilization (Lakić and Maličević, 2021). However, the chemical composition and nutritive value of silage are highly variable traits influenced by agroecological conditions, hybrid selection, applied agrotechnical practices, the phenological stage of the plant at harvest, and the technical quality of the forage harvester's performance (McDonald *et al*., 2021).

In terms of harvesting technology and mechanized silage processing, the ensiling of plant biomass using self-propelled forage harvesters represents the most energy-intensive operation of the process, directly dictating both productivity and the energetic value of the resulting forage. In this context, Malinović *et al.*, (2006) emphasize that the utilization of modern self-propelled forage harvesters provides significant operational advantages by increasing efficiency, reducing silage production costs, and incorporating electronic systems for automatic theoretical length of cut adjustment based on corn maturity, thereby minimizing the impact of human error and optimizing forage quality. In addition to energy consumption, the forage compaction technique itself constitutes a critical quality factor. Conducted research demonstrates that the degree of biomass compaction and the application of inoculants exert a key influence on the chemical composition of corn silage, whereas hybrid selection shows high justification primarily regarding the content of crude fibers and mineral matter (Ivetić, 2017).

The phenological stage of plant development at harvest decisively determines the in situ dry matter content and the ratio between vegetative mass and grain, which directly dictates its overall nutritive value (Garcia, 2016). Harvesting corn for silage before the milk line descends to half of the grain—namely, before reaching the optimal dry matter content (30–35% DM) leads to excessive silage effluent loss and an undesirable increase in acetic acid concentration within the silage mass (Huhtanen *et al.*, 2007). Conversely, an established dry matter content of 358±50.3 g kg^{-1} DM represents the upper limit of the desirable proportion in corn silage. Exceeding these values compromises adequate compaction and air evacuation from the silage mass, thereby provoking the proliferation of aerobic microorganisms and subsequent feed spoilage (Krüger *et al.*, 2020).

Silage preservation is a complex process based on the anaerobic fermentation of water-soluble carbohydrates, during which lactic acid bacteria synthesize organic acids that lower the pH value and preserve the feed in an unaltered form until the silo is opened (Vranić *et al.*, 2018). The utilization of high-quality silage in livestock nutrition represents the closest and most economical substitute for green forage, forming the foundation of modern and profitable cattle production (Dinić and Đorđević, 2005). Corn is an ideal crop for these purposes due to its high production of green mass, dry matter, and energy per hectare, along with the premium quality of the entire biomass (Mandić *et al.*, 2013). Within the structure of high-quality corn silage, grain accounts for an average of approximately 53%, while the remaining 47% consists of vegetative biomass (Braun *et al.*, 2009). Today, whole-plant corn silage represents an indispensable energy component in the rations of high-yielding dairy cows on farms across the Republic of Srpska.

Although the impact of climate factors on corn silage is well-known, the interaction between local agroecological conditions and the technical chopping parameters of forage harvesters under continental climate conditions in our country has not yet been sufficiently investigated. This study is based on the hypothesis that local specificities can significantly influence the chemical composition, dry matter content, and overall nutritive value of the forage. Moving from the aforementioned, the objective of this study was to determine the influence of agroecological conditions at the Gradiška and Bijeljina localities, as well as climate factors over a three-year period (2022–2024), on the yield, chemical composition, and energetic value of corn silage, alongside a simultaneous evaluation of the technical chopping parameters of forage harvesters.

MATERIAL AND METHODS

The investigation into the influence of location and agroecological conditions on corn silage quality was conducted at two localities within the framework of the program "Improvement of the Quality of Roughage and Concentrated Feed Produced and Stored on Farms of Agricultural Producers in the Republic of Srpska" over the 2022–2024 period. Throughout this three-year period, silage samples were collected from the same farms across two locations: Gradiška (L1) and Bijeljina (L2). On the farms included in this study, silage was prepared using corn hybrids belonging to the FAO 500 and 600 maturity groups. At both locations and across all three years, corn was harvested in the first half of September. The Gradiška locality is situated in an area dominated by a humid variant, whereas Bijeljina is located in an area dominated by a dry variant of the continental climate. At each location, four representative farms were selected, with production capacities ranging from 6 to 16 dairy cows.

Sampling of the corn silage was performed manually according to a standardized procedure. On each farm, sub-samples were collected from four separate locations within the silo and subsequently thoroughly homogenized to form a single composite, representative sample for that farm. From each farm, this representative sample was divided into two dedicated portions (aliquots). Both portions were packed into vacuum-sealed PVC bags, properly labeled, and a production inspection form was completed at the farm. The weight of each sample portion was approximately 1,000 grams. The first portion of the sample was utilized to determine the pH value and nutritive value indicators, while the second portion was used to determine the silage particle size distribution on separator sieves. In this manner, each individual farm was treated as an independent experimental unit, providing four replications per location (n=4 farms per locality).

Chemical analyzes of corn silage were performed in the laboratory for quality control of animal feed of the Agricultural Institute of the Republic of Srpska. Immediately after receiving the silage samples in the laboratory, the pH value, which is an indicator of the course of the fermentation process in the silage, was determined using a pH meter. The following nutritional value indicators were analyzed in corn silage samples: dry matter (DM, g kg^{-1}), crude protein (CP, g kg^{-1}), crude fiber (CF, g kg^{-1}) and crude ash (CA, g kg^{-1}).

The hygroscopic moisture content was determined by drying a homogenized sample of corn silage at 105 °C for 8 hours, and the moisture was determined according to the formula:

$$\text{moisture (\%)} = \frac{m_2 - m_1}{m_0} \cdot 100$$

Where:

m_0 - sample mass in grams;

m_1 - mass of vegeglas with the sample after drying;

m_2 - mass of vegeglas with the sample before drying.

After determining the moisture content, dry matter (DM) was calculated using the following formula:

DM (%) = 100 - moisture (%)

Crude protein (CP) content was determined using an automated analyzer based on the Kjeldahl method.

Crude fiber (CF) was determined according to the Henneberg-Stohmann method, while crude ash (CA) content was determined by incineration of samples in a muffle furnace at 550 °C.

The energy value of dry matter (MJ kg^{-1} DM) was calculated based on the results of chemical analyses, and was expressed as net energy for lactation (NEL).

The size of the silage particles was determined by sifting the silage samples through the sieves of the silage separator (Penn State particle separator). The silage separator consists of 3 sieves with different opening diameters, which are placed one above the other, and a bottom (box). The size distribution of silage particles is determined from a homogenized silage sample weighing 200 grams. The sample is poured into the upper sieve (holes 19 mm) of the separator. On a flat surface, the separator is shaken in one direction 5 times, and then rotated a quarter of a circle (1/4). During the shaking of the separator, there should be no vertical movements, that is, it should not rise from a flat surface. This procedure with one sample is repeated a total of 8 times, i.e. 40 movements of the separator back and forth (shakes) are performed. After the end of the procedure, the mass of steaks is silage, poured from each sieve (each box) into a container and weighed on a precision scale and recorded. The mass of the container is deducted from the balance. At the end of the weighing, the weight is recalculated into percentages for each sieve (box).

The analysis of weather conditions, during the duration of these tests, was performed on the basis of data obtained from hydrometeorological stations located in the area of the localities of Gradiška and Bijeljina.

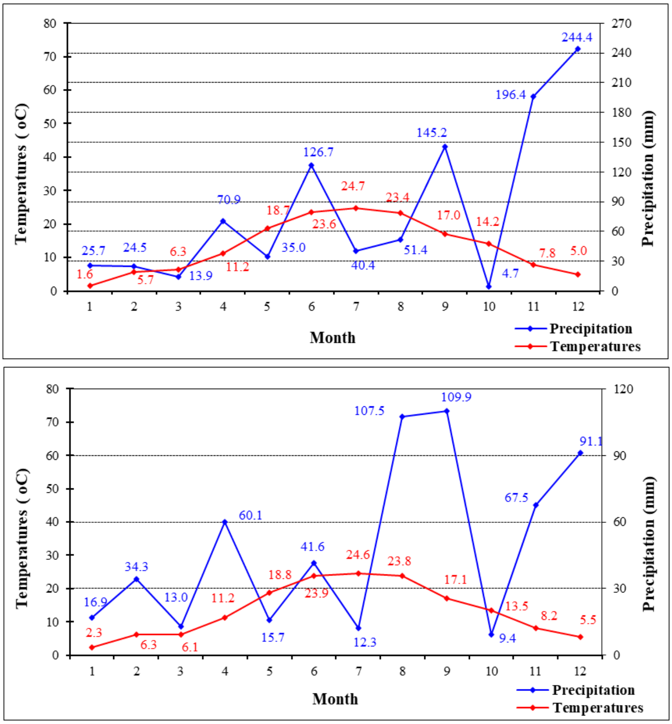
Statistical analysis

In the statistical processing of the corn silage quality indicators, descriptive statistical values were calculated: the mean, standard error of the mean (mean ± SE), and coefficient of variation (CV %). Since the single composite sample from each farm was divided into two dedicated portions (one for chemical analyses and the other for particle size separation), each of the four selected farms per location was treated as an independent biological replication, namely the primary statistical unit of observation (n=4) per location in each investigated year.

The obtained experimental results were subjected to a two-way analysis of variance (ANOVA), with geographical location (Factor A), year of investigation (Factor B), and their mutual interaction (AxB) considered as factors. The statistical significance of differences between treatment means was determined using the LSD (Least Significant Difference) test at significance levels of ($p<0.05$) and ($p<0.01$). All statistical computations were performed using the IBM SPSS Statistics software package (version 26.0).

Weather conditions

Throughout the testing period, precipitation and temperature were monitored, and data from the hydrometeorological stations in Bijeljina and Gradiška were used for this. Mean monthly air temperatures and total monthly precipitation for the period 2022–2024 are shown in Figures 1–3.



a)

b)

Figure 1. Precipitation and temperature in 2022, Gradiška (a) Precipitation and temperatures in 2022, Bijeljina (b)

In the period from April 10 to September 15, 2022, the amount of precipitation in the area of the Gradiška locality was 284.1 mm and was 38.5 mm higher than the amount of precipitation that fell during the silage corn vegetation in the Bijeljina locality. In the area of Bijeljina, the dry months were May, June and July, and in the area of Gradiška, July and August (Figure 1a and 1b). During the growing season, the lowest amount of precipitation was recorded in the locality of Bijeljina in July, when only 12.3 mm fell.

In the area of Bijeljina, the temperature at the time of corn sowing, i.e. in April, was higher than in the location of Gradiška (Figure 1a and 1b). The average temperature during the maize growing season at the Bijeljina locality was 18.2 °C, and the warmest month was July (24.6 °C). In the Gradiška area, the average temperature during the growing season was 18.1 °C.

During the vegetation period of the second year, 433.6 mm of precipitation was recorded at the Gradiška locality, which is a record during these tests. In the same period, there was 370.7 mm of precipitation in the locality of Bijeljina, which is 62 mm less than in the area of Gradiška. During these tests, the highest amount of precipitation was recorded in 2023. The driest months in the Gradiška locality were June, July and August (Figure 2v), and the lowest amount of precipitation was in June (20.6 mm). During the maize growing season, the dry months in the area of Bijeljina were July, August and September (Figure 2g).

The average temperature, during the maize growing season, in the Bijeljina locality was 19.7 °C, and in the Gradiška area 19.3 °C. At both locations, the average temperature during the growing season was higher than the previous year. The warmest month at both locations was July (Figure 2v and 2g).

v)

g)

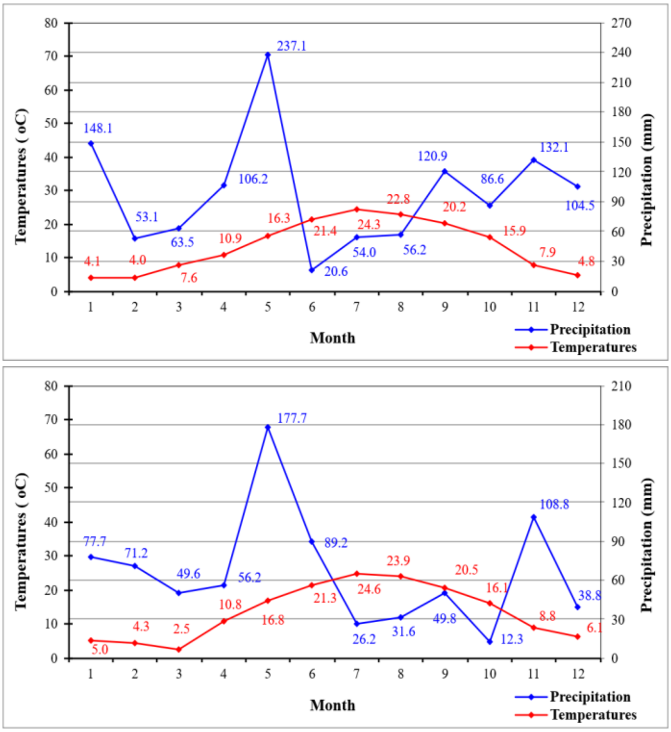
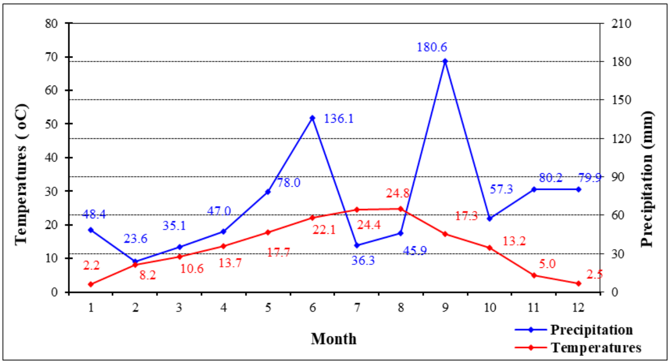


Figure 2. Precipitation and temperature in 2023, Gradiška (v) Precipitation and temperatures in 2023, Bijeljina (g)

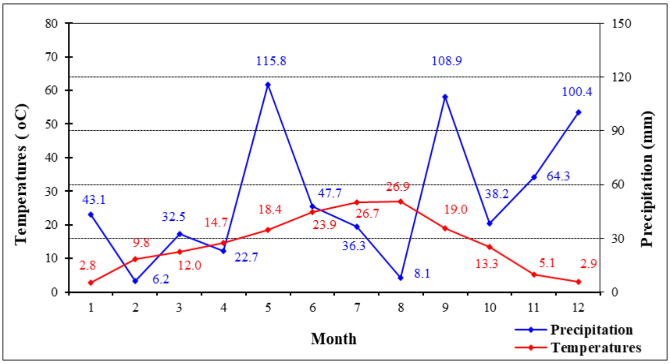
In the third year of testing, the amount of precipitation at the location of Gradiška was 393.0 mm, and was 107.5 mm higher than in the area of Bijeljina. In the location of Bijeljina, the most precipitation, during the corn growing season, was recorded in May, and in the area of Gradiška in June. The dry months in the locality of Gradiška were July and August, and in the area of Bijeljina June, July, and August (Figure 3d and 3e).

In the Gradiška location, the average temperature was 20.0 °C, and in the Bijeljina area 21.6 °C. At both locations, this was the warmest year during these tests. The warmest month in the locality of Bijeljina was August with an average daily temperature of 26.9 °C, and in the locality of Gradiška July with a temperature of 24.7 °C.

During these tests, there were two dry months in the Gradiška locality during the summer, and three in the Bijeljina area, which affected the yield, but also the indicators of the nutritional value of corn silage.



d)



e)

Figure 3. Precipitation and temperature in 2024, Gradiška (d) Precipitation and temperatures in 2024, Bijeljina (e)

RESULTS AND DISCUSSION

The results of chemical analyzes and the energy value of corn silage, stored on the family farms of Gradiška (L1) and Bijeljina (L2), are shown in Table 1. The results in Table 2 show the variance analysis of indicators of fermentation processes, nutritional, and energy values of corn silage.

The three-year fermentation dynamics indicators of the corn silage are presented in Table 1. The average pH value of the silage at the Gradiška locality (L1) was 3.91±0.12, with the minimum value recorded in 2023 (3.84) and the maximum in 2024 (4.04). At the Bijeljina locality (L2), the average three-year pH value was 3.93±0.20, ranging from 3.84 (2023) to 3.98 (2024). The coefficient of variation (CV) was low at both localities (3.13% for L1; 5.13% for L2). The analysis of variance (Tab. 2) confirmed that location (A), year of investigation (B), as well as their interaction (A x B) exerted no statistically significant effect ($p > 0.05$) on the pH variation, indicating that the observed differences between localities L1 and L2 were not statistically justified.

These results demonstrate that the pH values of most samples at both locations were within the optimal limits (3.8–4.2) for whole-plant corn silage, which characterizes excellent quality silage and indicates a stable and proper lactic acid fermentation process across all investigated treatments. The obtained data are in complete agreement with regional studies conducted in the Western

Balkans. Over multi-year quality analyses of corn silage in Bosnia and Herzegovina, Glavić *et al.,* (2014) determined that average pH values ranged from 3.81 to 4.03, indicating proper fermentation of the evaluated silages. Similarly, Domaćinović *et al.,* (2022) reported a uniform pH value ranging from 3.82 to 3.94. A somewhat wider variation range (from 3.3 to 4.3) in horizontal silos and silage piles within the areas of Derventa, Mrkonjić Grad, and Prijedor was noted by Lakić *et al.*, (2020), which can be attributed to varying management conditions on the individual farms.

From a biochemical perspective, Sriharsha (2017) emphasizes that the pH value is a key indicator of fermentation dynamics and mass stability during storage and preservation within the silo. According to Grbeša (2016), corn silages in which processes proceeded in the correct direction, where water-soluble carbohydrates were utilized as a substrate for lactic acid bacteria standardly exhibit a pH value between 3.8 and 4.2. A rapid drop in pH below the 4.0 threshold effectively preserves water-soluble carbohydrates, halts the growth of enterobacteria, and prevents the proliferation of undesirable butyric acid bacteria (Clostridia). In well-preserved silages, the pH value should vary from 3.7 to 4.0, accompanied by a lactic acid concentration of 3% to 6% on a dry matter basis (Kung *et al.*, 2018). Closely linked to these biochemical processes is the chopping of the plant material. Proper chopping of the plant biomass to an appropriate length enables a more intensive release of cell sap. The released water-soluble carbohydrates serve as the primary substrate for lactic acid bacteria for the rapid synthesis of preservatives, which directly ensures a swift decline in acidity and long-term stability of the anaerobic medium.

The dry matter (DM) content at the Gradiška locality varied from 318.65 g kg^{-1} DM (2022) to 392.80 g kg^{-1} DM (2024), with a three-year average of 351.72±44.59 g kg^{-1} DM. At the Bijeljina locality, a considerably lower average DM content of 285.68±37.30 g kg^{-1} DM was recorded, with the minimum value observed in 2023 (270.93 g kg^{-1} DM) and the maximum in 2024 (309.10 g kg^{-1} DM). The results of the analysis of variance (Tab. 2) indicate that the DM content was under a strong and highly significant influence of location ($p<0.01$) and a significant influence of the investigation year ($p<0.05$), while the interaction (AxB) did not exhibit a significant effect ($p>0.05$).

The optimal dry matter content for corn silage prepared at the dough stage of grain maturity ranges between 300 and 350 g kg^{-1} (30–35% DM), as this range ensures an unhindered course of fermentation processes, secure storage, and a positive effect on animal productivity (Nkosi *et al.,* 2009). The DM content in corn silage is primarily determined by the phenological stage at which the plant is ensiled, but also by the selection of the corn hybrid (De Boever, 1999). The significantly lower DM values determined in Bijeljina (below 300 g kg^{-1}) are a direct consequence of the locality specific agroecological conditions or an earlier harvest stage, such as the milk-dough maturity stage. According to Huhtanen *et al.,* (2007), premature ensiling of corn specifically before the milk line appears at half of the grain is undesirable because the silage mass retains a significantly lower dry matter content than optimal. During the testing of several corn hybrids, at three locations in Canada, according to Guyader *et al.*, (2018) the content of dry matter was from 267-491 g kg^{-1}, and crude protein from 61.6-87.5 g kg^{-1}. That environmental factors play a decisive role is also indicated by research reported by Mitrík *et al.*, (2026), emphasizing that the interaction of temperature and precipitation during the growing season can exert a two times stronger effect on trait variability and the DM percentage of silage from year to year compared to the genotype (hybrid) itself. On the other hand, harvesting corn at the full grain maturity stage is also undesirable because it negatively affects the quality of the stored feed (Domaćinović *et al.*, 2022). Silages prepared from older, overripe corn plants are characterized by a lower content of water-soluble carbohydrates and an elevated dry matter proportion. This significantly compromises mass compaction, air evacuation, and the establishment of stable anaerobic conditions within the silo, while simultaneously resulting in a lower energetic value of the feed.

Table 1. Flow indicator of fermentation processes and indicators of nutritional and energy value of corn silage at the locations of Gradiška and Bijeljina, 2022-2024

Treatments		pH value	Dry matter-DM (g kg^{-1})	Crude proteins – CP (g kg^{-1})	Crude Fiber (CF) (g kg^{-1})	Crude Ash (CA) (g kg^{-1})	Net Energy for Lactation (NEL) (MJ kg^{-1} DM)
Location (A)	Year (B)						
Gradiška (L_1)	2022	3.86	318.65	75.05	238.18	41.13	6.12
	2023	3.84	343.70	68.23	232.38	41.28	6.32
	2024	4.04	392.80	69.19	257.20	37.60	6.41
	Average± $S_{\bar{x}}$	3.91 ± 0.12	351.72 ± 44.59	70.82 ± 7.76	242.58 ± 21.92	40.00 ± 5.39	6.28 ± 0.20
	CV (%)	3.13	12.68	10.96	9.04	13.48	3.17
Bijeljina (L_2)	2022	3.97	277.00	76.50	270.48	45.25	5.96
	2023	3.84	270.93	74.30	288.08	41.28	6.15
	2024	3.98	309.10	84.45	270.65	32.25	6.24
	Average± $S_{\bar{x}}$	3.93 ± 0.20	285.68 ± 37.30	78.40 ± 9.01	276.40 ± 39.56	38.59 ± 11.45	6.12 ± 0.16
	CV (%)	5.13	13.06	11.48	14.31	28.92	2.65

The crude protein content (Tab. 1) at the Gradiška locality averaged 70.82±7.76 g kg^{-1}, whereas a higher average proportion of 78.40±9.01 g kg^{-1} was recorded in Bijeljina, with a maximum of 84.45 g kg^{-1} DM achieved in 2024. The analysis of variance indicates a statistically significant dependence of the crude protein content exclusively on the location factor ($p<0.05$), while the influence of the year and their mutual interaction was not statistically significant ($p>0.05$).

The crude protein content in silage can be linked to soil fertility, applied technology, the amount of nitrogen fertilizers applied, drought-induced climate stress, as well as the selection of the hybrid itself. This is also pointed out by

Mandić *et al.,* (2018), who emphasize that agroecological conditions across different production years, along with the selection of the optimal harvest moment, decisively influence the synthesis and final proportion of crude protein in the forage mass. Accordingly, the higher protein level determined in Bijeljina may be induced by the specific soil type or a better nitrogen supply to the plants during the growing season at that locality.

The obtained crude protein values at both localities are within the framework of reference regional research. Thus, Domaćinović *et al.,* (2022) state that the crude protein content in the analyzed corn silages ranged from 37.0 to 107.0 g kg^{-1}, with an average of 71.4 g kg^{-1}, which is in complete agreement with our results in Gradiška. Somewhat lower average values compared to our findings are reported by Vranić *et al., (*2004), according to whom corn silage stored on family farms in Croatia contains an average of 65.0 g kg^{-1} of crude protein, as well as Gmižić *et al.,* (2016) with an established average of 66.0 g kg^{-1} DM. Similar ranges are reported by Glavić *et al.,* (2014), who determined a crude protein content of 63.1 to 69.4 g kg^{-1} in the territory of Bosnia and Herzegovina, accompanied by a crude fiber content of 316.9 to 339.9 g kg^{-1}.

In contrast to proteins, the crude fiber proportion exhibited an inverse trend. A significantly higher three-year crude fiber proportion was recorded at the Bijeljina locality (276.40±39.56 g kg^{-1} DM), ranging from 270.48 to 288.08 g kg^{-1} DM depending on the investigation year. Conversely, a considerably lower three-year average was determined at the Gradiška locality (242.58±21.92 g kg^{-1} DM), varying from 232.8 g kg^{-1} DM to 257.2 g kg^{-1} DM. The crude fiber content was under a highly significant influence of location ($p<0.01$), whereas the investigation year and its mutual interaction did not exert a statistically significant effect on its content ($p>0.05$).

Table 2. Results of analysis of variance (ANOVA)

Indicators	LSD	Location (A)	Year (B)	A x Б
pH Value	0.05	0.14	0.17	0.24
	0.01	0.19	0.23	0.33
Dry matter (DM)	0.05	30.28*	37.08*	52.44
	0.01	41.47**	50.80	71.84
Crude Protein (CP)	0.05	7.05*	8.64	12.22
	0.01	9.66	11.84	16.74
Crude Fiber (CF)	0.05	28.83*	35.31	49.93
	0.01	39.49**	48.37	68.40
Crude Ash (CA)	0.05	7.49	9.17	12.97
	0.01	10.26	12.56	17.77
Net Energy for Lactation (NEL)	0.05	0.12*	0.15*	0.21
	0.01	0.17**	0.21**	0.29

The high crude fiber content at the Bijeljina locality was above the desirable threshold for whole-plant silage and is directly linked to the lower determined dry matter percentage. This implies a higher proportion of lignified vegetative mass (stalk and leaf) relative to the corn cob and grain. In well-prepared corn silages, it is desirable for the fiber content to be as low as possible. Optimal values for silage harvested at the ideal maturity stage range between 180 and 220 g kg^{-1} DM, with the total crude fiber content preferably remaining below the 250 g kg^{-1} threshold. In corn silage, every percentage increase in crude fiber above the critical 22% (220 g kg^{-1} DM) drastically reduces the overall nutritional value. This occurs because, as the plant ages and matures, it intensively accumulates lignin—a substance that rumen microorganisms cannot degrade. The causes of elevated crude fiber content may include an unfavorable hybrid selection, a poor cob-to-stalk ratio due to drought, inadequate agrotechnical practices, climate stress, excessively low cutting height during ensiling, as well as delayed harvesting of overmature biomass.

In contrast, the lower crude fiber values at the Gradiška locality indicate a substantially more favorable proportion of cobs in the total biomass. This morphological composition directly enhances the digestibility of organic matter in the rumen of ruminants, which is in accordance with the classic principles reported by Van Soest *et al.,* (1991). The results obtained at both localities also fall within the ranges reported in recent regional literature. Thus, Kamalak *et al.*, (2003) state that the crude fiber content in corn silage ranges from 230.0 to 254.0 g kg^{-1}, which aligns with our findings from Gradiška. Wider variation ranges (from 130.18 to 272.42 g kg^{-1}, with an average of 188.21 g kg^{-1}) are highlighted by Vranić *et al.,* (2022) on farms in Croatia. Furthermore, Dubljević *et al.,* (2016) in their investigations recorded an average crude fiber content of 168.35 g kg^{-1}, accompanied by a crude ash content of 46.84 g kg^{-1} on a dry matter basis.

The average three-year crude ash proportion in the corn silage was 40.00±5.39 g kg^{-1} DM for the Gradiška locality and 38.59±11.45 g kg^{-1} DM for the Bijeljina locality. The analysis of variance (Tab. 2) determined that location, year, and their interaction exerted no statistically significant influence on the values of this parameter ($p>0.05$). The absence of statistical significance and the uniformity of the obtained results across the investigated years indicate a high level of technical hygiene during the harvesting and processing of the silage mass at both observed localities.

The determined values are in complete accordance with literature reports, according to which well-preserved whole-plant corn silage contains an average of between 44.0 and 45.0 g kg^{-1} DM of crude ash (Domaćinović *et al.,* 2022). Given that the ash content at both localities was below the critical threshold of 50.0 g kg^{-1} DM (Hoffman, 2021), it can be concluded that no soil contamination of the forage occurred during machinery operation, thereby minimizing the risk of introducing harmful spores of anaerobic bacteria into the silage. The crude ash content in contaminated silages can reach up to 100.0 g kg^{-1} DM (Ward, 2011), representing a direct consequence of soil contamination (Domaćinović *et al.*, 2022). The main causes of elevated values of this parameter include unfavorable agrometeorological conditions (such as precipitation during harvest or crop flooding), the introduction of soil by machinery wheels during silo filling and compaction, and excessively low cutting height (Ward, 2011). The intensity of soil contamination and the subsequent microbiological status are primarily influenced by the cutting height; mowing at a height lower than 15 cm increases the probability of gathering soil particles from the ground surface, which is why a minimum cutting height of 20 cm is recommended in forage processing technology. Contamination of the silage mass with soil has negative implications for animal health status. Introduced bacteria of the genus Clostridium, under conditions of poor fermentation and compromised aerobic status of the silage, can produce substantial amounts of toxins. The consumption of such forage in dairy cow nutrition causes severe health disorders, manifesting through the occurrence of diarrhea, botulism, and, in extreme cases, lethal outcomes in animals (Queiroz *et al.,* 2018).

The energetic value of the corn silage, expressed as net energy for lactation (NEL), at the Gradiška locality ranged from 6.12 MJ kg^{-1} DM (in 2022) to 6.41 MJ kg^{-1} DM (in 2024), with a three-year average of 6.28±0.20 MJ kg^{-1} DM. At the Bijeljina locality, a statistically significantly lower average NEL was recorded, amounting to 6.12±0.16 MJ kg^{-1} DM, with a variation from 5.96 MJ kg^{-1} DM to 6.24 MJ kg^{-1} DM across the investigated years. The three-year analysis of variance (Tab. 2) confirmed that the energetic value of the silage was under a highly significant influence of location ($p<0.01$) and a significant influence of the production year ($p<0.05$), whereas the interaction of these factors (AxB) did not exert a statistically significant effect ($p>0.05$).

Chronologically, the highest energetic value was determined in 2024 at the Gradiška locality (6.41 MJ kg^{-1} DM), directly coinciding with the highest dry matter proportion and the lowest crude fiber content recorded in that production year. More favorable agroecological conditions during the critical phenofases of grain filling at the Gradiška locality enabled maximum starch synthesis, which explains the high NEL values. Conversely, the increased crude fiber proportion at the Bijeljina locality adversely affected the overall energetic potential of the produced silages. According to Fitzgerald and Murphy (1999), the energy value of silage is largely related to the starch content of the corn grain. In well-preserved and properly stored corn silages, the energetic value expressed as NEL should exceed the threshold of 6.50 MJ kg^{-1} DM. Silages from the farms at both investigated localities achieved lower energetic values than the desirable optimum. For comparison, Petrovska *et al.,* (2015) reported average NEL values ranging from 6.50±0.09 MJ kg^{-1} DM to 6.60±0.06 MJ kg^{-1} DM. The established energetic potential of the silage on the investigated farms in Gradiška and Bijeljina is comparatively close to the NEL values of the corn silage utilized by Van Hoeij *et al.,* (2017) in dairy cow feeding trials (6.40 MJ kg^{-1} DM). The lower energetic value of the produced corn silage can be caused by agrotechnical and technological shortcomings, as well as unfavorable agroecological or agroclimatic factors that disrupt the optimal ratio between grain and the vegetative mass of the plant.

The chop length of the silage mass exerts a multifaceted influence on compaction quality, the fermentation profile, and feed intake intensity. According to the standards reported by Heinrichs (2013), a technologically properly adjusted forage harvester should ensure particle size distribution on the Penn State Particle Separator (PSPS) sieves within the following optimal ranges: the upper sieve with a 19 mm aperture (3–8%), the middle sieve with an 8 mm aperture (45–65%), the lower (third) sieve with a 4 mm aperture (20–30%), and the bottom pan for particles smaller than 4 mm (less than 10%).

The distribution of pieces (particles) of silage according to length, on individual sieves of the silage separator (Penn State Particle Separator), is expressed as a percentage and shown in table 3.

Table 3. Length of particles (cuts) of corn silage determined by sieving through the sieve system of the silage separator (Penn State Particle Separator)

Number of sieves	Particle size (piece) which are retained on the sieve (mm)	Desirable values of the distribution of cuts (particles) on sieves (%)	Deviation of the length of steaks (particles) from the desired value of distribution on sieves (%)							
			Gradiška				Bijeljina			
			2022	2023	2024	Average	2022	2023	2024	Average
I	>19	3-8	50	50	-	33.33	50	-	-	16.67
II	8-19	45-65	-	-	-	-	-	-	-	
III	4-8	20-30	50	25	-	25.00	75	50	-	41.67
Box	< 4	< 10	50	25	-	25.00	75	-	-	25.00

The analysis of the obtained results revealed significant deviations on individual sieves during the investigated three-year period. At both observed localities, the highest deviations in particle length relative to the target values were recorded in the first year of the investigation (2022). At the L1 locality (Gradiška), deviations were determined on the upper (19 mm) and lower (4 mm) sieves, as well as in the bottom pan during the first two years. Throughout this period, a high proportion of chops larger than 19 mm was recorded on the upper sieve at the L1 locality, with an average three-year deviation of 33.30% compared to the recommended values, while the deviation on the lower sieve amounted to 25.00%, matching the value recorded in the bottom pan for particles smaller than 4 mm. In the third year of the investigation at this locality, no statistically significant deviation from the desired particle size distribution was determined on any sieve.

On the farms located at the L2 locality (Bijeljina), the deviation of chop length relative to the target values was also evidenced during the first and second years of the research. During the first year, deviations reached as high as 75.00%

on the lower sieve and in the bottom pan, whereas in the second year, deviations were recorded exclusively on the lower sieve. The deviation in chop distribution on the upper sieve (19 mm) at the L2 locality was determined only during the first year. The average three-year deviation relative to the reference values at the L2 locality was 16.67% on the upper sieve, 41.67% on the lower sieve, and 25.00% in the bottom pan. During the third year (2024), no deviation relative to the desired chop distribution values was recorded at the L2 locality. This trend of complete stabilization of the physical structure and the absence of deviations in the third year at both localities clearly indicates successful techno-managerial adjustment of the self-propelled forage harvesters and increased awareness among farmers regarding the importance of controlling the chop length. Žurak *et al.,* (2018) also highlight high variability in the field, stating that half or more than half of the corn silage samples on large farms had contents on individual sieves outside the optimal ranges.

Proper chopping of plant biomass is a prerequisite for the release of cell sap rich in water-soluble carbohydrates, which serve as a substrate for lactic acid bacteria. This optimizes mass compaction within the silo facility, evacuates oxygen, and ensures a rapid drop in pH value, which constitutes a crucial condition for preservation. An excessive proportion of long particles (>19 mm), such as that determined at the L1 and L2 localities during the first two years, compromises compaction within the silo, leading to the retention of air pockets, extending the aerobic phase, and favoring the proliferation of molds and yeasts, thereby directly inducing nutrient losses and increasing silage susceptibility to spoilage upon opening the facility.

Deviations on the upper sieve (>19 mm) have direct economic and physiological consequences on dairy cattle. According to research conducted by Grant *et al.,* (2018), a higher proportion of chops exceeding 19 mm in corn silage adversely affects feed intake, increases feed sorting losses, and extends the feeding time of cows due to sorting (separation) of the ration at the feed bunk. Cows sort the ration by using their muzzle to reject long particles while consuming smaller, concentrate-rich portions, which in the long term reduces milk and milk component yields due to the rejection of structural fiber. On the other hand, a surplus of particles below 4 mm (bottom pan) also compromises the metabolic status of the animals. As stated by Domaćinović *et al.,* (2022), silages with a higher proportion of fine particles exhibit an increased intensity of microbial degradation and accelerated synthesis of volatile fatty acids in the rumen, leading to subclinical or clinical rumen acidosis. The lack of particles above 8 mm reduces chewing activity and saliva secretion, which acts as a natural buffer, further jeopardizing the stability of the rumen environment.

CONCLUSIONS

Based on the three-year investigations into corn silage quality at the Gradiška (L1) and Bijeljina (L2) localities, the following key conclusions and recommendations for production practice can be drawn:

Agroclimatic conditions, primarily precipitation deficits and elevated temperatures during the growing season at the L2 locality, directly necessitated an earlier forage harvest at the milk and milk-dough stages of maturity. This consequently resulted in a significantly lower dry matter content, reduced energetic value (NEL), and a considerably higher average content of structural fiber (crude fiber). These conditions led to poorer ear development and a dominant proportion of lignified vegetative mass within the total silage mass at the L2 locality. Conversely, ensiling corn at the optimal dough and full maturity stages at the L1 locality ensured a more favorable raw material morphological composition, maximum energetic potential, and an optimal nutrient balance, highlighting the critical importance of precisely determining the harvest moment depending on agroecological factors.

Highly stable and uniform pH values across both observed localities confirm that the technological procedures of compaction and sealing of the silage mass on the farms were conducted in accordance with professional standards. The low variability in pH values demonstrates that a high level of technological discipline during the early anaerobic phase can successfully compensate for and neutralize the negative impacts of variations in the chemical composition of the incoming field raw material.

The high coefficient of variation for crude ash content on certain farms at the L2 locality indicates occasional shortcomings in harvesting hygiene and the technical preparation of ensiling. To prevent soil contamination of the silage mass and minimize the risk of introducing harmful spores of anaerobic bacteria, production practices strictly require rigorous control over machinery operation and raising the plant cutting height to a minimum of 20 cm.

Significant deviations in particle size distribution on the Penn State separator during the first two years of the research at both locations indicate initially inadequate theoretical length of cut adjustments on the self-propelled forage harvesters, as well as sub-optimal kernel processor performance. The complete stabilization of the chop structure and the absence of deviations from the recommended norms in the third year of the investigation (2024) represent the most significant applied outcome of this study. This trend unequivocally proves the effectiveness of continuous farmer education and successful field-level techno-managerial adjustment of the machinery. Standardizing the chop length and optimizing kernel processor performance in the third year are crucial for maximizing feed intake and starch digestibility, thereby ensuring the stability of the rumen environment and long-term improvements in the economic efficiency of milk production across the observed localities.

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