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Nutritional Value and Chemical Composition of Corn Silage Depending on Cutting Height and Forage Losses

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ABSTRACT

The study presents the effect of cutting height (10, 15 and 30 cm) on yield, nutritional value and chemical composition of silage corn. The experiment was carried out under dryland conditions and the silage corn was harvested with three types of self-propelled silage harvesters. Cutting height increased linearly with increasing operating speed of silage harvesters. For all types of silage harvesters, the cutting height of 30 cm had a statistically significant ($p \leq 0.05$) effect on losses of yields. The numerical value of the R^2 factor (from $R^2 = 0.8978$ to 0.9896) shows a strong dependence in all harvesters for all three cutting heights. The regression coefficients (b) show a significant deviation from the theoretical cutting height at 10 and 15 cm (b = 0.6676 and b = 0.6715), and very significant (b = 2.0249) at the theoretical cutting height of 30 cm. With an increase in cutting height, the nutritional value of silage increased. At a cutting height of 30 cm, during the test period in all types of harvesters, the crude protein (CP) content was significantly ($p \leq 0.05$) higher than at a cutting height of 10 cm (harvester C = 6.94% at 10 cm, harvester B = 8.15% at 30 cm). The cutting height of 30 cm influenced a significantly ($p \leq 0.05$) lower crude fiber (CF) content of harvester Claas Jaguar 850 (21.19%), compared to John Deere 6810 (24.33%) at a height of 10 cm. The crude ash content (CAsh) did not vary significantly under the influence of cutting height. Starch content was statistically higher ($p \leq 0.05$) in all types of silage harvesters during the test at a cutting height of 30 cm (28.2% harvester New Holland FX 28, 33.8% harvester Claas Jaguar 850). The content of calcium (Ca) was significantly higher at a height of 30 cm for harvesters John Deere 6810 and Claas Jaguar 850 in the third year, while no significant difference was found for harvester New Holland FX 28. For phosphorus (P), there was no significant difference depending on the cutting height, but it did exist depending on the year.

Keywords: silage harvester, cutting height, crude protein, crude fiber, starch, mineral matter.

INTRODUCTION

The quality of silage primarily depends on the nutritional value and chemical composition of the ensiled material. The corn plant has a high yield biomass and nutritional value and is very suitable for ensiling (Neylon and Kung, 2003; Dehpouri et al., 2022). Corn silage is one of the main components of forage in animal nutrition (Khan et al., 2014). Ensiling is a process of anaerobic conservation of finely chopped silage by lactic acid fermentation. This process minimizes the loss of nutrients in the silage. The high concentration of sugar in the corn plant enables successful fermentation and the production of the required amount of lactic acid, which as a preservative sterilizes the silage material, helps Ca resorption and does not change the acid-base balance. The goal of silage preparation is the production of bulk food with a high dry matter content, energy and highly digestible nutrients (Kung et al., 2018). Good digestibility of corn silage is ensured by the high content of carbohydrates, and the lower content of crude protein and crude ash (Szymańska et al., 2018). Knowledge of the chemical composition of corn silage is important in order to enable the feeding of animals with a balanced meal of high nutritional value (Zicarelli et al., 2023). According to Motta et al. (2020) and Schmidt et al. (2015), the relationship between the chemical composition

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and the nutritional value of corn silage allows for a more balanced diet and economic milk production of dairy cows.

When preparing corn silage, must be pay attention to the time of the beginning of the harvest and the corn cutting height (Mandić et al., 2020). A study by Bumb et al. (2016), showed that the quality of forage and yield is significantly affected by the time of harvest. The harvest itself can be early or late. The loss of nutritional yield due to higher cutting height was much lower when maize was harvested at a late maturity stage (Aoki et al., 2013). The optimal period for harvesting and shredding the entire corn plant is at a moisture content of 65-70%, when the share of the cob in the mass of the entire corn plant is up to 40%, the grain is in the stage of waxy maturity (dry matter content 30-35%), with maximum starch content. The choice and use of appropriate agricultural machinery (silage harvesters) can be an important factor on which the chemical composition and nutritional value of silage depends. The production of quality fodder and profitable production in animal husbandry rely, among other things, on the efficient operation of silage harvesters (Valge et al., 2021). The cutting height of corn affects the chemical composition and nutritional value of corn silage (Kennington et al., 2005; Aoki et al., 2013). With an increase in the cutting height, there is an increase in the nutritional quality of corn silage, but also a decrease in the total yield and an increase in losses. To improve the nutritional value of silage of high-protein and high-yielding maize varieties, Zhao et al. (2018), recommend increasing the cutting height. Hulse et al. (2017), recommend harvesting corn at a height of 40 cm because it provides the best balance between the quantity and nutritional quality of the prepared silage. Kennington et al. (2005) and Diepersloot et al. (2022) prove that stem cutting heights over 60 cm result in a decrease in crude protein content in silage.

When evaluating the quality of corn silage, the crude protein content is treated as a positive parameter, and the crude fiber content as a negative parameter. Bulky food with a high crude protein content has a high energy value (Zhang et al., 2018). Caetano et al. (2011), suggest that with higher cutting heights, the nutritional value and chemical composition of silage improves because the crude protein content increases. At the same time, the content of crude ash decreases, which is a consequence of the increase in the share of grains in corn silage. With an increase in the proportion of grain in the silage, there is an increase in the concentration of starch and a decrease in the crude fiber content (Bernard et al., 2004; Horst et al., 2021), which significantly affects the increase in the nutritional value of the silage (Diepersloot et al., 2022). In addition to starch, calcium and phosphorus are considered the primary minerals in the diet of dairy cows, important for the skeletal structure of the animals. Crude ash is a source of minerals in food and has no energy value. A high content of crude ash in silage indicates possible contamination with soil particles or other impurities, resulting in reduced feed intake, low fiber digestibility and reduced absorption of minerals in the digestive tract of animals (Khan et al., 2007). The test results of self-propelled silage harvesters showed high correlation dependence between movement speed, cutting height and forage losses. With an increase in the movement speed of all tested harvesters, forage losses increased due to the increase in cutting height (Barać et al., 2015). The study (Miljković et al., 2021) states that with an increase in the cutting height, losses in corn biomass increase, which represents agro waste of appropriate nutritional value that remains on the plot and can be used.

The aim of the research is to examine the influence of cutting height on the chemical composition, nutritional value of the silage mass and losses in forage during the harvesting of the whole corn plant and preparation of silage using different types of self-propelled silage harvesters.

MATERIAL AND METHODS

The research was conducted during three growing seasons: 2018, 2019 and 2020 in the municipality of Kruševac (43°33'35.02" N;

21º29'55.61" E) in central Serbia. The soil on which the experiments were set up was moderately acidic, without the presence of $CaCO_3$, moderately provided with humus (2.59%) and nitrogen (0.16%), and extremely poor in phosphorus (4 mg/100g). The silage is prepared in the late stage of maturity under dryland conditions (without irrigation) from whole plants of silage corn hybrid KWS Mikado belonging to FAO ripening group 550, high nutritional value of silage.

Harvesting was done in the same plots with three types of self-propelled forage harvesters: New Holland FX 28 (Type A), Claas Jaguar 850 (Type B) and John Deere 6810 (Type C), with theoretical stem cutting heights of 10 cm, 15 cm and 30 cm. The yields of green mass were determined from random locations in the field (Kung et al., 2008), with 5 repetitions each (Kowalik et al., 2013), according to the years of the study for each theoretical cutting height of stems on an area of 10 m^2, and then recalculated per area of one hectare. As corn was grown in dryland conditions, the yield, chemical composition and nutritional value of the tested hybrid were significantly affected by the temperature and especially by the amount of precipitation. A study (Zhao et al., 2022) showed that the climatic factor has a key role on the nutritional value of corn silage. Changes in air temperature and precipitation during the years of the study caused a difference in the yield and quality of corn silage (Liimatainen et al., 2022).

Average monthly values of air temperature and amount of precipitation for the area where tests were carried out in the vegetation period from 2018-2020, compared with the multi-year average (2008-2017), are shown in Table 1.

Table 1. Mean monthly air temperatures (ºC) and monthly amount of rainfall (mm)

Year	2018		2019		2020		2008-2017	
Month	T mean (ºC)	Precipitation (mm)	T mean (ºC)	Precipitation (mm)	T mean (ºC)	Precipitation (mm)	T mean (ºC)	Precipitation (mm)
Mar.	6.6	110.3	9.2	24.1	7.7	92.3	7.7	64.1
April	16.5	41.2	13.0	59.2	11.8	41.6	12.7	70.4
May	18.9	74.4	14.9	73.5	15.9	103.1	16.8	86.6
June	20.9	109.1	22.6	67.5	19.7	130.8	21.0	64.8
July	21.6	149.3	22.7	47.1	21.6	187.5	23.0	52.6
Aug.	22.4	61.5	23.1	83.1	22.0	74.3	22.6	33.2
Sept.	17.2	9.4	18.5	4.8	18.8	15.4	17.9	42.6
Mar.-Sept.	17.72	552.2	17.71	359.3	16.78	645.0	17.39	414.3

The yield height was directly dependent on the air temperature and the amount of precipitation, especially in the summer period (June, July, August). The mean value of the air temperature during the growing season did not deviate significantly in the three-year period of our tests. It was approximately the same in the first and second year (17.72ºC and 17.71ºC), and lower (16.78ºC) in the third year of the study. However, significant deviations were noted in the amount of precipitation by the years of the study, and also in relation to the multi-year average values. The lowest rainfall of 359.3 mm was recorded in the second year, and the highest (645.0 mm) in the third year of the study. The values of the amount of precipitation significantly influenced the yield.

The working speed of the silage harvesters was determined by the standard chronometric method by measuring the movement time of the silo harvester along a track of 50 m length using a PCE LDM 50 laser rangefinder, while the chronometry was based on a TFA Dostmann Triple Time XL-Digitaler 3-fach Timer (Al-Gaadi, 2018). The cutting height of the stems was determined at the point of determining the losses by measuring the height of all the cuttings on the corresponding surface for each trial (5 trials with 5 repetitions). Based on the obtained parameters, the average for each trial was determined. Losses represent the parts of the stem above the given theoretical cutting height that are not cut. By measuring the cut parts remaining above the theoretical cutting height in the working width of the self-propelled silage harvesters, in a length of one meter, the losses in relation to the yield and the set cutting height were determined. All stems that exceeded the theoretical height were cut manually and collected in paper bags. Weight measurements of all samples were made using a KERN PCD 10K0.1 digital balance.

Using the random sample method, each sample was divided into four parts, which constituted a repetition. The content of crude proteins, crude fiber and crude ash, starch, calcium and phosphorus was determined by appropriate laboratory methods. The crude protein content (total nitrogen) was determined according to the standard Kjeldahl method (Thiex et al., 2002), by decomposing organic matter with concentrated sulfuric acid (H_2SO_4) in the presence of catalysts (K_2SO_4 and $CuSO_4$, which accelerate the reaction) and titrating the resulting ammonia. The obtained values were multiplied by a coefficient of 6.25. The crude fiber content was determined by a method based on treating samples with sulfuric acid solution (H_2SO_4) and sodium hydroxide solution (NaOH) of standard concentration (Thiex et al., 2009). The crude ash content was determined by the method (Thiex et al., 2012) of burning the samples at a temperature of 600ºC for 2 hours. After that, the sample is cooled and weighed immediately. The starch content was determined by the enzymatic-calorimetric method (Hall, 2015). Samples were mixed with acetic acid buffer ($C_2H_4O_2$) and heat-stable α-amylase. The starch value is calculated by multiplying the enzymatically released glucose by 0.9 and then dividing by the mass of the received sample. The content of calcium and phosphorus was determined by standard spectrometric methods (Albu et al., 2012), with detection limits of 10 mg/kg for Ca, and 50 g/kg for P. The obtained experimental data were processed using a free software package (R Core Team, 2018). Tukey's multiple range test and coefficient of variation were used to test treatment effects. A linear regression model was used to analyze the influence of the movement speed of silage harvesters on the stems cutting height (Marqes de Sá, 2007).

RESULTS AND DISCUSSION

The working speed of silage harvesters significantly affects the cutting height of corn stalks in all three types of the tested silage harvesters (Figure 1). The cutting height increased linearly with the increase in the working speed of the self-propelled silage harvesters, which is also stated by other authors in their research (Barać et al., 2015; Ramm et al., 2023).

In relation to the theoretical cutting height of 10 cm (Figure 1A), the largest deviation with the achieved cutting height of up to 13.6 cm was for the harvester C (regression slope coefficient was b = 0.6676), and the smallest for the harvester B (b = 0.6360) with an achieved cutting height of up to 12.5 cm, which is more preferable. The numerical value of the R^2 factor shows a strong dependence for all three types of silo harvesters. The values ranged from 0.8978, 0.9002 and 0.9101 (A, B and C), respectively.

At a theoretical cutting height of 15 cm (Figure 1B), the increase was the smallest and almost identical during the operation of the harvester B (regression slope coefficient was b = 0.6509) and the harvester A (b = 0.6514) with realized cutting heights of up to 18.3 cm, i.e. 18.4 cm, and the largest during the operation of the harvester C (b = 0.6715) with an achieved height of up to 18.7 cm. In all types of the tested harvesters, R^2 factors show a very strong dependence on A (R^2 = 0.9741), B (R^2 = 0.9613) and C (R^2 = 0.9896).

In relation to the theoretical cutting height of 30 cm (Figure 1C), all three types of silage harvesters show a very strong sensitivity to the increase in working speed: the harvester C with an achieved cutting height of up to 38.6 cm (the regression slope coefficient was b = 1.7095), the harvester A with an achieved cutting height of up to 38.1 cm (b = 1.9029) and the harvester B with an achieved cutting height of up to 37.3 cm (b = 2.0249). In all cases, for all three types of silo harvesters, the value of the R^2 factor was above 0.96 (C = 0.9688, B = 0.9712 and A = 0.9761).

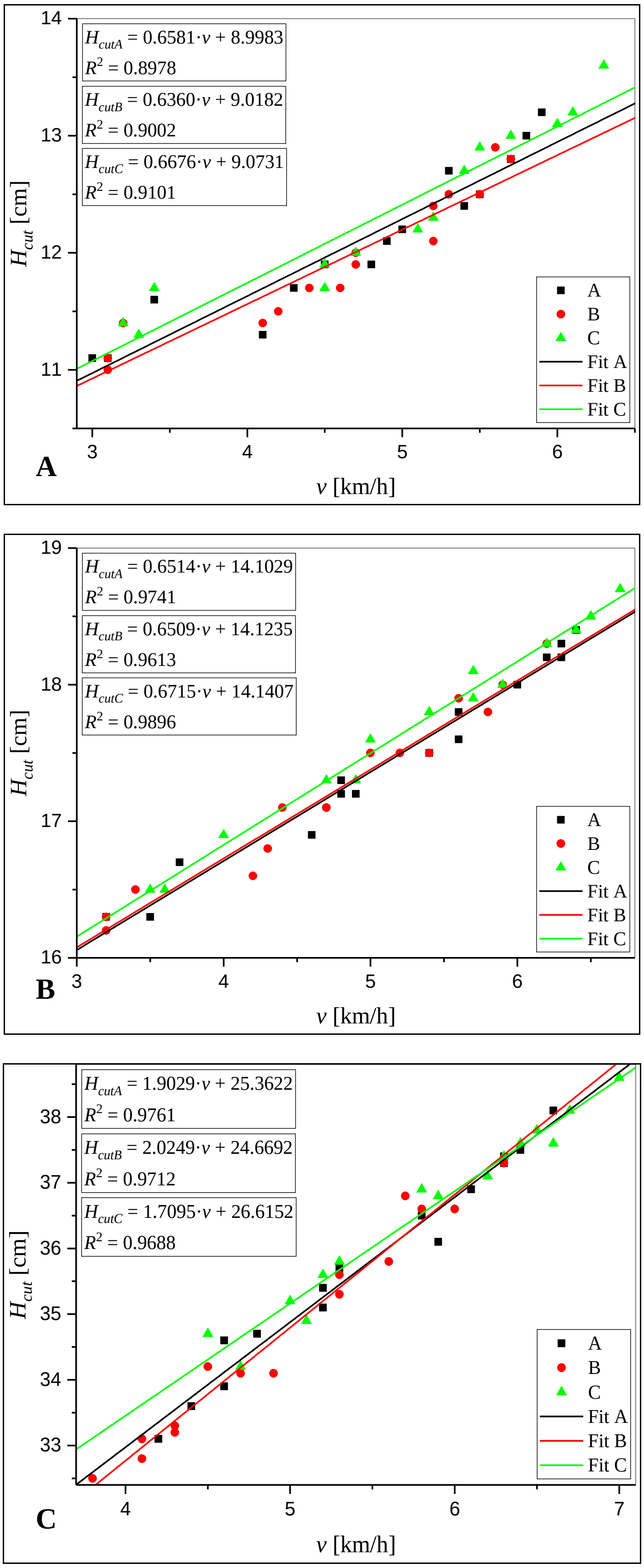

Figure 2. Cutting height H_{cut} vs. mower working speed v: (A) for a theoretical cutting height of 10 cm, (B) for a theoretical cutting height of 15 cm, (C) for a theoretical cutting height of 30 cm

With an increase in cutting height, there is an increase in forage losses and a decrease in the total yield of the examined self-propelled silage harvesters. Minimal losses in silage mass at theoretical cutting heights of 10, 15 and 30 cm during the three-year test period were recorded during the operation of the harvester B (from 740 kg ha^{-1} at a height of 10 cm, to 1,185 kg ha^{-1} at a height of 30 cm in 2019) (Table 2).

Table 2. Realized losses of green mass in relation to the theoretical cutting height of silage harvesters (type A, B, C)

Cutting height (cm)		2018		2019		2020	
		Losses *(kg ha^{-1})*	Yield *(kg ha^{-1})*	Losses *(kg ha^{-1})*	Yield *(kg ha^{-1})*	Losses *(kg ha^{-1})*	Yield *(kg ha^{-1})*
A	10	878^{bB}	28.766^{aB}	790^{bB}	26.380^{aC}	1050^{bA}	33.250^{aA}
	15	982^{bB}	27.654^{aB}	885^{bC}	25.412^{aC}	1169^{bA}	31.937^{abA}
	30	1.488^{aB}	25.602^{bB}	1.331^{aB}	23.467^{bC}	1.803^{aA}	29.869^{bA}
	$\overline{X}$	1.116	27.341	1.002	25.086	1.341	31.685
	CV	29.2	5.87	28.8	5.91	30.2	5.38
B	10	820^{bB}	28.766^{aB}	740^{bC}	26.380^{aC}	982^{bA}	33.250^{aA}
	15	892^{bB}	27.654^{aB}	807^{bB}	25.412^{aC}	1076^{bA}	31.937^{abA}
	30	1.319^{aB}	25.602^{bB}	1.185^{aC}	23.467^{bC}	1.622^{aA}	29.869^{bA}
	$\overline{X}$	1.010	27.341	911	25.086	1.227	31.685
	CV	26.7	5.87	26.3	5.91	28.2	5.38
C	10	962^{bB}	28.766^{aB}	870^{bB}	26.380^{aB}	1134^{bA}	33.250^{aA}
	15	1064^{bB}	27.654^{aB}	967^{bC}	25.412^{aC}	1282^{bA}	31.937^{abA}
	30	1.635^{aB}	25.602^{bB}	1.473^{aC}	23.467^{bC}	1.996^{aA}	29.869^{bA}
	$\overline{X}$	1.220	27.341	1.103	25.086	1.471	31.685
	CV	29.7	5.87	29.3	5.91	31.3	5.38

Type A - New Holland FX 28; Type B - Claas Jaguar 850; Type C - John Deere 6810;
Tukey's test statistical significance levels: $p \leq 0.05$, small letters a, b. for columns each type of harvester individually, capital letters A, B. for the trait in the year influence row.

The maximum values of losses for all three theoretical cutting heights were achieved during the operation of the harvester C (from 1,134 kg ha^{-1} at a height of 10 cm, to 1,996 kg ha^{-1} at a height of 30 cm in 2020). For all harvesters, a cutting height of 30 cm had a statistically significant ($p \leq 0.05$) effect on higher losses, but also a lower yield compared to cutting heights of 10 and 15 cm in all years of the study, as indicated by earlier research (Neylon and Kung, 2003; Kennington et al., 2005; Hulse et al., 2017) who state that quality silage obtained at a significantly higher cutting height is not justified because the yield decreases (7.3-15 %), forage losses and food production costs increase. Higher cutting heights are recommended only at the mature stage of corn because there is less loss of silage nutritional value (Wu and Roth, 2005; Aoki et al., 2013). Also, climatic conditions (year 2020) had a significant ($p \leq 0.05$) influence on the yield level, but also on the losses during harvesting with all types of harvesters and at all cutting heights, compared to two less favorable years (2018 and 2019).

Table 3. Effect of cutting height of silage harvesters (type A, B, C) on the chemical composition of corn silage

Cutting height (cm)		2018			2019			2020		
		CP %	CF %	CAsh %	CP %	CF %	CAsh %	CP %	CF %	CAsh %
A	10	7.01^{bA}	24.16^{bA}	5.81^{aA}	7.03^{bA}	24.24^{aA}	5.98^{aA}	7.07^{bA}	23.44^{aA}	5.69^{aA}
	15	7.10^{bA}	23.83^{abA}	5.58^{aA}	7.13^{bA}	24.17^{aA}	5.77^{aA}	7.14^{bA}	22.76^{abA}	5.53^{aA}
	30	8.05^{aB}	22.02^{bAB}	5.34^{aA}	7.96^{aA}	22.27^{bA}	5.05^{aA}	8.11^{aB}	21.29^{bB}	5.50^{aA}
	$\overline{X}$	7.387	23.337	5.577	7.373	23.560	5.600	7.440	22.497	5.573
	CV	7.80	4.94	4.21	6.92	4.74	8.71	7.81	4.88	1.83
B	10	7.06^{bA}	23.45^{aA}	5.70^{aA}	7.10^{bA}	23.64^{aA}	5.54^{aA}	7.09^{bA}	23.12^{aA}	5.83^{aA}
	15	7.14^{bA}	23.11^{aA}	5.55^{aA}	7.19^{bA}	22.54^{abA}	5.42^{aA}	7.23^{bA}	22.51^{abA}	5.36^{abA}
	30	8.07^{aA}	21.90^{bA}	5.15^{aA}	8.01^{aA}	22.13^{bA}	5.28^{aA}	8.15^{aA}	21.19^{bB}	4.63^{bA}
	$\overline{X}$	7.423	22.675	5.467	7.433	22.770	5.413	7.490	22.273	5.273
	CV	7.56	4.83	5.20	6.75	3.43	2.40	7.69	4.43	11.47
C	10	6.94^{bA}	24.33^{aA}	6.00^{aA}	6.95^{bA}	24.26^{aA}	5.93^{aA}	6.99^{bA}	23.80^{aA}	5.84^{aA}
	15	7.09^{abA}	23.71^{abA}	5.66^{aA}	7.07^{abA}	23.67^{abA}	5.69^{aA}	7.18^{bA}	22.70^{abA}	5.41^{aA}
	30	7.98^{aA}	22.24^{bA}	5.30^{aA}	7.81^{aA}	22.32^{bA}	5.40^{aA}	8.02^{aA}	21.45^{bA}	5.06^{aA}
	$\overline{X}$	7.337	23.427	5.653	7.277	23.417	5.673	7.397	22.650	5.437
	CV	7.66	4.58	6.19	6.40	4.25	4.68	7.41	5.19	7.19

Type A - New Holland FX 28; Type B - Claas Jaguar 850; Type C - John Deere 6810; CP - crude protein; CF - crude fiber; CAsh - crude ash; Tukey's test statistical significance levels: $p \leq 0.05$, small letters a, b. for columns each type of harvester individually, capital letters A, B. for the trait in the year influence row.

The results of our tests show that the cutting height of the corn stalks significantly influenced the nutritional value and chemical composition of the prepared corn silage. At a cutting height of 30 cm in all types of silage harvesters during the test, the crude protein (CP) content was significantly ($p \leq 0.05$) higher compared to a cutting height of 10 cm (Table 3). The maximum crude protein content of 8.15% at a cutting height of 30 cm was achieved by the operation of the harvester B in 2020. The minimum content of 6.94% was achieved by the operation of the harvester C in 2018 at a cutting height of 10 cm. At the same time, the cutting height of 30 cm influenced a significantly ($p \leq 0.05$) lower crude fiber (CF) content of 21.19% which was achieved by the work of the harvester B, compared to the cutting height of 10 cm where the crude fiber content by the work of the harvester C was 24.33%. The crude ash content (CAsh) did not vary significantly under the influence of cutting height.

The results of this study are consistent with the findings of other researchers (Kung et al., 2008; Caetano et al., 2011; Kowalik et al., 2013; Szymańska et al., 2018) and prove that with an increase in cutting height, the content of crude protein (CP) increases, while the content of crude fiber (CF) and crude ash (CAsh) decreases, which improves the chemical value of corn silage.

Table 4. Effect of cutting height of silage harvesters (type A, B, C) on the mineral composition of silage corn

Cutting height (cm)		2018			2019			2020		
		Starch %	Ca %	P %	Starch %	Ca %	P %	Starch %	Ca %	P %
A	10	28.7^{bB}	0.14^{bB}	0.21^{aB}	28.2^{bB}	0.13^{aB}	0.20^{aB}	29.4^{bA}	0.17^{aA}	0.23^{aA}
	15	30.2^{abA}	0.14^{bB}	0.21^{aB}	29.6^{abA}	0.13^{aB}	0.20^{aB}	30.5^{bA}	0.17^{aA}	0.23^{aA}
	30	32.6^{aAB}	0.16^{aB}	0.21^{aB}	31.8^{aB}	0.14^{aC}	0.21^{aB}	33.4^{aA}	0.18^{aA}	0.24^{aA}
	$\overline{X}$	30.500	0.147	0.210	29.867	0.133	0.203	31.100	0.173	0.233
	CV	6.45	7.87	0.00	6.08	4.33	2.84	6.64	3.33	2.47
B	10	29.1^{bA}	0.14^{bB}	0.21^{aB}	29.7^{bA}	0.14^{aB}	0.20^{aB}	29.2^{bA}	0.17^{bA}	0.23^{aA}
	15	31.1^{abA}	0.15^{abB}	0.21^{aB}	30.6^{abA}	0.14^{aB}	0.21^{aB}	31.9^{abA}	0.18^{abA}	0.24^{aA}
	30	33.2^{aAB}	0.16^{aB}	0.22^{aB}	32.5^{aB}	0.15^{aB}	0.21^{aB}	33.8^{aA}	0.19^{aA}	0.24^{aB}
	$\overline{X}$	31.133	0.150	0.213	30.933	0.143	0.207	31.633	0.180	0.237
	CV	6.59	6.67	2.71	4.62	4.03	2.79	7.31	5.56	2.44
C	10	28.3^{bB}	0.13^{bB}	0.20^{aB}	28.6^{bB}	0.13^{aB}	0.19^{aB}	29.2^{bA}	0.16^{bA}	0.23^{aA}
	15	29.8^{abB}	0.14^{abB}	0.21^{aB}	29.4^{abB}	0.14^{aB}	0.20^{aB}	30.5^{abA}	0.17^{abA}	0.23^{aA}
	30	31.7^{aAB}	0.15^{aB}	0.21^{aB}	31.3^{aB}	0.14^{aB}	0.20^{aB}	32.1^{aAB}	0.18^{aA}	0.23^{aA}
	$\overline{X}$	29.933	0.140	0.207	29.767	0.137	0.197	30.600	0.170	0.230
	CV	5.69	7.14	2.79	4.66	2.94	2.94	4.75	5.88	0.00

Type A - New Holland FX 28; Type B - Claas Jaguar 850; Type C - John Deere 6810; Ca - calcium;
P - phosphorus; Tukey's test statistical significance levels: $p \leq 0.05$, small letters a, b. for columns each type of harvester individually, capital letters A, B. for the trait in the year influence row.

Depending on the years of testing, the type of silage harvesters and the cutting height, the variability of the crude protein (CP) content was very uniform (from CV = 6.40 harvester C in 2019, to CV = 7.81 harvester A in 2020), the variability of the crude fiber (CF) content was even lower and also uniform, while the variability of crude ash (CAsh) content was with higher differences (from CV = 1.83 harvester A in 2020 to CV = 11.47 harvester B in 2020).

The evaluation of the nutritional value of corn silage depends to a significant extent on the concentration of mineral components - starch, calcium and phosphorus. Starch is the main source of metabolic energy in corn silage (Khan et al., 2007). With an increase in cutting height, fiber content decreases and starch content increases (Lynch et al., 2015; Szymańska et al., 2018). Ferraretto et al. (2018) and Horst et al. (2021), state that by increasing the cutting height, there is an increase in the share of grains, and thus the concentration of starch in the prepared silage, which increases the nutritional value of the silage.

Starch was statistically higher ($p \leq 0.05$) in all types of silage harvesters in all years of testing at a cutting height of 30 cm with a maximum of 33.8% in 2020 (harvester B), compared to a minimum of 28.2% (harvester A) in 2019 at a cutting height of 10 cm (Table 4).

At the same level of statistical significance and cutting height of 30 cm, calcium (Ca) showed higher values in 2018 for all harvesters. In 2019, there was no statistical significance, but the peak values did exist. In 2020, the content of calcium (Ca) was significantly higher after harvesting with harvesters C and B at a cutting height of 30 cm compared to a cutting height of 10 cm, while no significant difference was found with harvester A. For phosphorus (P), there was no significant difference depending on the cutting height, but it did exist depending on the year. The achieved values of the content of mineral components in corn silage in our tests are compatible with the results reported by other authors (Kennington et al., 2005; Wu and Roth, 2005; Kung et al., 2008; Lynch et al., 2015; Hulse et al., 2017), and a study (Zhao et al., 2018) recommends that the cutting height of high-starch silage corn varieties should be moderately reduced to increase silage quality and yield.

During our research, the highest and positive correlation dependence ($p \leq 0.001$) existed between silage yield and calcium (Ca) and phosphorus (P) content (Table 5).

Table 5. Pearson's correlation coefficients (r) of the investigated parameters of corn silage harvested in a three-year period (n=9)

Cutting height (cm)	Parameters	Losses %	CP %	CF %	CAsh %	Starch %	Ca %	P %
10	Yield (kg ha^{-1})	0.877**	0.222	-0.626	-0.106	0.465	0.922***	0.963***
	Losses (kg ha^{-1})		-0.239	-0.219	0.206	0.148	0.685*	0.752*
	CP %			-0.807**	-0.763*	0.761*	0.521	0.422
	CF %				0.614	-0.765*	-0.802**	-0.710*
	Cash %					-0.909***	-0.368	-0.257
	Starch %						0.669*	0.593
	Ca %							0.949***
15	Yield (kg ha^{-1})	0.853**	0.521	-0.612	-0.364	0.608	0.945***	0.950***
	Losses (kg ha^{-1})		0.151	-0.316	-0.254	0.145	0.721*	0.708*
	CP %			-0.802**	-0.469	0.826**	0.658	0.722**
	CF %				0.743*	-0.765*	-0.772*	-0.766*
	Cash %					-0.485	-0.592	-0.507
	Starch %						0.738*	0.756*
	Ca %							0.968***
30	Yield (kg ha^{-1})	0.830**	0.288	-0.953***	-0.336	0.618	0.962***	0.932***
	Losses (kg ha^{-1})		0.065	-0.649	-0.055	0.088	0.669	0.608
	CP %			-0.667*	-0.041	0.518	0.401	0.244
	CF %				0.415	-0.774*	-0.981***	-0.977***
	Cash %					-0.373	-0.438	-0.419
	Starch %						0.766*	0.792*
	Ca %							0.944***

* $p \leq 0.05$, **$p \leq 0.01$, ***$p \leq 0.001$, ns not signifcant (nsp≥0.05); CP - crude protein; CF - crude fiber; CAsh - crude ash; Ca - calcium; P – phosphorus.

At all cutting heights and between calcium (Ca) and phosphorus (P) there was a highly significant ($p \leq 0.001$) and positive correlation dependence, while between silage yield and losses the dependence was of a lower level of significance ($p \leq 0.01$) but also positive. On the other hand, there was a negative correlation dependence between the content of crude proteins (CP) and crude fiber (CF) from r = -0.667, at the significance level of $p \leq 0.05$, at a cutting height of 30 cm, to r = -0.807 and r = -0.802, up to the significance level of $p \leq 0.01$, at a cutting height of 10 and 15 cm. There was a highly significant ($p \leq 0.001$) and negative dependence between crude ash (Cash) and starch of r = -0.909, at a cutting height of 10 cm, as well as between yield and crude fiber (CF) of r = -0.953 and between crude fiber (CF) and calcium (Ca) of r = -0.981 at a cutting height of 30 cm (Table 5).

CONCLUSIONS

It was observed that climatic conditions had a significant ($p \leq 0.05$) effect on yield and losses. For all types of silage harvesters, a cutting height of 30 cm had a statistically significant ($p \leq 0.05$) effect on losses of yield compared to cutting heights of 10 and 15 cm in all years of the study. The minimum losses at the cutting height of 30 cm were achieved by the operation of silo harvester B (1.185 kg ha-1), and the maximum by the operation of silo harvester C (1.996 kg ha-1). The cutting height of corn stalks had a significant effect on the chemical composition and nutritional value of the prepared silage. In all types of silage harvesters, the content of crude proteins (CP) at a cutting height of 30 cm was significantly ($p \leq 0.05$) higher than at a cutting height of 10 cm. The maximum values of crude protein (CP) content of 8.15% were achieved during the operation of harvester B. The cutting height of 30 cm influenced a significantly ($p \leq 0.05$) lower crude fiber (CF) content of harvester B (21.19 %) compared to the cutting height of 10 cm, where the crude fiber (CF) content of harvester C was 24.33%. The crude ash content (CAsh) did not vary significantly under the influence of cutting heights. Starch in all types of silage harvesters was statistically higher ($p \leq$ 0.05) at a cutting height of 30 cm with a maximum of 33.8% of harvester B compared to a minimum of 28.2% of harvester A at a cutting height of 10 cm. At the same level of statistical significance and cutting height of 30 cm, calcium (Ca) was significantly higher after harvesting with harvesters C and B, while no significant difference was found with harvester A. For phosphorus (P), there was no significant difference depending on the cutting height.

Summarizing the results of our comparative tests of self-propelled silage harvesters regarding the effect of cutting height on the nutritional value and chemical composition of silage corn, preference is given to harvester B, which achieved the best results. In conditions of preparation of silage at a later stage, a cutting height of 30 cm is recommended because it ensures the best balance between the quantity of silage to be prepared and its nutritional quality. We must state that the lack of irrigation of the areas under silage corn is a major limiting factor in silage production in Serbia.

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REFERENCES

Albu, A., Pop, I.M., Radu-Rusu, C., 2012. *Calcium (Ca) and phosphorus (P) concentration in dairy cow feeds*. Lucrări Ştiinţifice - Seria Zootehnie, 57(17): 70-74. https://www.uaiasi.ro/firaa/Pdf/Pdf_Vol_57/Aida_Albu.pdf

Al-Gaadi, K.A., 2018. *Impact of raking and baling patterns on alfalfa hay dry matter and quality losses*. Saudi J. Biol. Sci., 25(6): 1040-1048. https://doi.org/10.1016/j.sjbs.2018.02.009

Aoki, Y., Oshita, T., Namekawa, H., Nemoto, E., Aoki, M., 2013. *Effect of cutting height on the chemical composition, nutritional value and yield, fermentative quality and aerobic stability of corn silage and relationship with plant maturity at harvest*. Grassl. Sci., 59(4): 211-220. https://doi.org/10.1111/grs.12033

Barać, S., Vuković, A., Biberdžić, M., Djikić, A., Milenković, B., Djokić, D., 2015. *Result of the exploiting trials on the silage combines in preparing the silage for dairy cows.* In: Fift international conference Research people and actual tasks on multidisciplinary sciences. Lozenec, Bulgaria, 1: 156-160. https://www.cabdirect.org/cabdirect/abstract/20163058578

Bernard, J.K., West, J.W., Trammell, D.S., Cross, G.H., 2004. *Influence of corn variety and cutting height on nutritive value of silage fed to lactating dairy cows*. J. Dairy Sci., 87(7): 2172-2176. https://doi.org/10.3168/jds.S0022-0302(04)70037-5

Bumb, I., Garnier, E., Bastianelli, D., Richarte, J., Bonnal, L., Kazakou, E., 2016. *Influence of management regime and harvest date on the forage quality of rangelands plants: the importance of dry matter content.* AoB PlantS, 8: plw045. https://doi.org/10.1093/aobpla/plw045

Caetano, H., Oliveira, M.D.S., Freitas, Júnior J.E., Rêgo, A.C., Carvalho, M.V., Rennó, F.P., 2011. *Nutritional characteristics and in vitro digestibility* *of silages from different corn cultivars harvested at two cutting heights*. R. Bras. Zootec., 40(4): 708-714. https://doi.org/10.1590/S1516-35982011000400002

Dehpouri, F., Tari, D.B., Niknejad, Y., Amoli, H.F., Amiri, E., 2022. *Study of nitrogen fertilization management on corn yield and nitrogen use efficiency in the southern Caspian Sea region*. Rom. Agric. Res., 39: 385-390. https://doi.org/10.59665/rar3935

Diepersloot, E.C., Heinzen, C., Saylor, B.A., Ferraretto, L.F., 2022. *Effect of cutting height, microbial inoculation, and storage length on fermentation profile and nutrient composition of whole-plant corn silage*. Transl. Anim. Sci., 6(2): 1-10. https://doi.org/10.1093/tas/txac037

Ferraretto, L.F., Shaver, R.D., Luck, B.D., 2018. *Silage review: Recent advances and future technologies for whole-plant and fractionated corn silage harvesting*. J. Dairy Sci., 101(5): 3937- 3951. https://doi.org/10.3168/jds.2017-13728

Hall, M.B., 2015. *Determination of dietary starch in animal feeds and pet food by an enzymatic-colorimetric method: Collaborative study*. J. AOAC Int., 98(2): 397-409. https://doi.org/10.5740/jaoacint.15-012

Horst, E.H., Bumbieris, V.H., Neumann, M., Lopez, S., 2021. *Effects of the Harvest Stage of Maize Hybrids on the Chemical Composition of Plant Fractions: An Analysis of the Different Types of Silage*. Agriculture, 11(8): 786. https://doi.org/10.3390/agriculture11080786

Hulse, J., Neumann, M., Ueno, R.K., Heker, J.C., Figueira, D.N., Sandini, I.E., Muller, M.M., Horst, E.H., Vigne, G.L.D., 2017. *Nutrient balance in the soil and nutritive characteristics of maize silage cut at different heights.* Sem. Ci. Agr., 38: 3779-3795. http://dx.doi.org/10.5433/1679-0359.2017v38n6p3779

Kennington, L.R., Hunt, C.W., Szasz, J.I., Grove, A.V., Kezar, W., 2005. *Effect of cutting height and genetics on composition, intake, and digestibility of corn silage by beef heifers*. J. Anim. Sci., 83(6): 1445-1454. https://doi.org/10.2527/2005.8361445x

Kowalik, I., Kruczyk, H., Michalski, T., 2013. *Chemical composition and nutritive value of maize stems depending on the cutting height of plants at harvest*. J. Cent. Eur. Agric., 14(4): 1261-1270. https://doi.org/10.5513/JCEA01/14.4.1336

Kung, L., Moulder, B.M., Mulrooney, C.M., Teller, R.S., Schmidt, R.J., 2008. *The effect of silage cutting height on the nutritive value of a normal corn silage hybrid compared with brown midrib corn silage fed to lactating cows*. J. Dairy Sci., 91(4): 1451-1457. https://doi.org/10.3168/jds.2007-0236

Kung, L., Shaver, R.D., Grant, R.J., Schmidt, R.J., 2018. *Silage review: Interpretation of chemical, microbial, and organoleptic components of silages*. J. Dairy Sci., 101(5): 4020-4033. https://doi.org/10.3168/jds.2017-13909

Khan, Z., Ashraf, M., Hussain, A., 2007. *Evaluation of Macro Mineral Contents of Forages: Influence of Pasture and Seasonal Variation.* Asian-Aust. J. Anim. Sci., 20(6): 908-913. https://doi.org/10.5713/ajas.2007.908

Khan, N.A., Yu, P., Ali, M., Cone, J.W., Hendriks, W.H., 2014. *Nutritive value of maize silage in relation to dairy cow performance and milk quality*. J. Sci. Food. Agric., 95(2): 238-252. https://doi.org/10.1002/jsfa.6703

Liimatainen, A., Sairanen, A., Jaakkola, S., Kokkonen, T., Kuoppala, K., Jokiniemi, T., Mäkelä, P.S.A., 2022. *Yield, Quality and Nitrogen Use of Forage Maize under Different Nitrogen Application Rates in Two Boreal Locations*. Agronomy, 12: 887. https://doi.org/10.3390/agronomy12040887

Lynch, J.P., Baah, J., Beauchemin, K.A., 2015. *Conservation, fiber digestibility, and nutritive value of corn harvested at 2 cutting heights and ensiled with fibrolytic enzymes, either alone or with a ferulic acid esterase-producing inoculant*. J. Dairy Sci., 98(2): 1214-1224. https://doi.org/10.3168/jds.2014-8768

Mandić, V., Bijelić, Z., Krnjaja, V., Đorđević, S., Brankov, M., Mićić, N., Stanojković, A., 2020. *Harvest time effect on quantitative and qualitative parameters of forage maize*. J. Anim. Plant Sci., 31: 103-107. https://doi.org/10.36899/JAPS.2021.1.0198

Marques de Sá, P.J., 2007. *Applied Statistics using SPSS, STATISTICA, MATLAB and R (second edition*). Springer-Verlag, Berlin Heidelberg, 271-328. https://link.springer.com/book/10.1007/978-3-540-71972-4

Miljković, M.G., Davidović, S.Z., Djukić-Vuković, A.P., Ilić, M.V., Simović, M.B., Rajilić-Stojanović, M.D., Dimitrijević-Branković, S.I., 2021. *Utilization of agro-industrial by-products as substrates for dextransucrase production by Leuconostoc mesenteroides T3: process optimization using response surface methodology*. Hem. Ind., 75(3): 135-146. https://doi.org/10.2298/HEMIND200710015M

Motta, A.C.V., Araujo, E.M., Broadley, M.R., Young, S.D., Barbosa, J.Z., Prior, S.A., Schmidt, P., 2020. *Minerals and potentially toxic elements in corn silage from tropical and subtropical Brazil.* R. Bras. Zootec., 49: e20190214. https://doi.org/10.37496/rbz4920190214

Neylon, J.M., and Kung, L., 2003. *Effects of Cutting Height and Maturity on the Nutritive Value of Corn Silage for Lactating Cows*. J. Dairy Sci., 86(6): 2163-2169. https://doi.org/10.3168/jds.S0022-0302(03)73806-5

R Core Team, 2018. R: *A Language and Environment for Statistical Computing (version 3.4.4)*. R

Foundation for Statistical Computing, Vienna, Austria. https://www.r-project.org/

Ramm, S., Hasler, M., Reckleben, Y., Hartung, E., 2023. *Single Pass Grain Corn Harvest and Stubble Shredding: Performance of Three Corn Header Configurations as Effected by Harvesting Speed and Cutting Height.* Agriculture, 13: 833. https://doi.org/10.3390/agriculture13040833

Schmidt, P., Novinski, C.O., Junges, D., Almeida, R., Souza, C.M., 2015. *Concentration of mycotoxins and chemical composition of corn silage: A farm survey using infrared thermography*. J. Dairy Sci., 98: 6609-6619. https://doi.org/10.3168/jds.2014-8617

Szymańska, G., Sulewska, H., Faligowska, A., Ratajczak, K., 2018. *Evaluation of nutritive value and quality of maize (Zea mays L.) silage depending on cutting height and ensiling additive*. Fragm. Agron., 35(1): 94-105. https://doi.org/10.26374/fa.2018.35.09

Thiex, N.J., Manson, H., Anderson, S., Persson, J.A., 2002. *Determination of Crude Protein in Animal Feed, Forage, Grain, and Oilseeds by Using Block Digestion with a Copper Catalyst and Steam Distillation into Boric Acid: Collaborative Study*. J. AOAC Int., 85(2): 309-317. https://doi.org/10.1093/jaoac/85.2.309

Thiex, N., 2009. *Evaluation of analytical methods for the determination of moisture, crude protein, crude fat, and crude fiber in distillers dried grains with solubles*. J. AOAC Int., 92(1): 61-73. https://doi.org/10.1093/jaoac/92.1.61

Thiex, N., Novotny, L., Crawford, A., 2012. *Determination of ash in animal feed: AOAC official method 942.05 revisited.* J. AOAC Int., 95(5): 1392-1397. https://doi.org/10.5740/jaoacint.12-129

Valge, A., Sukhoparov, A., Papushin, E., Dobrinov, A., 2021. *Evaluation effectiveness of forage harvesters in silage preparation*. IOP Conf. Ser.: Earth Environ. Sci., 699: 012050. https://doi.org/10.1088/1755-1315/699/1/012050

Wu, Z., and Roth, G., 2005. *Considerations in managing cutting height of corn silage.* Extension publication DAS 03-72, College Park, Pennsylvania State University: 3-72. https://extension.psu.edu/considerations-in-managing-cutting-height-of-corn-silage

Zicarelli, F., Sarubbi, F., Iommelli, P., Grossi, M., Lotito, D., Tudisco, R., Infascelli, F., Musco, N., Lombardi, P., 2023. *Nutritional Characteristics of Corn Silage Produced in Campania Region Estimated by Near Infrared Spectroscopy (NIRS)*. Agronomy, 13(3): 634. https://doi.org/10.3390/agronomy13030634

Zhang, J., Iwaasa, A.D., Han, G., Gu, C., Wang, H., Jefferson, P.G., Kusler, J., 2018. *Utilizing a multi-index decision analysis method to overall assess forage yield and quality of C3 grasses in the western Canadian prairies*. Field Crops Research, 222: 12-25. https://doi.org/10.1016/j.fcr.2018.03.007

Zhao, M., Feng, Y., Shi, Y., Shen, H., Hu, H., Luo, Y., Xu, L., Kang, J., Xing, A., Wang, S., Fang, J., 2022. *Yield and quality properties of silage maize and their influencing factors in China*. Sci. China Life Sci., 65: 1655-1666. https://doi.org/10.1007/s11427-020-2023-3

Zhao, X.J., Zhang, L.Y., Liu, S., XiaoHui, A., Yue, K.Z., Zhang, Y.G., 2018. *Effects of cutting height on quality of different varieties of whole plant corn silage*. Anim. Nutr., 30(8): 3239-3246. https://www.cabdirect.org/cabdirect/abstract/20183374370